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DATA PACKAGE

FOR

STRUCTURAL EVALUATION OF CANDIDATE SPACE SHUTTLE THERMAL PROTECTION SYSTEMS

By

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D180-15093-1

Prepared For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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Contract NAS 1-11154

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ABSTRACT

This document contains all of the data required for submittal under Contract NAS 1-11154, "Structural Evaluation of Candidate Space Shuttle Thermal Protection Systems". Included are design requirements, structural data, instrumentation data, recommended test conditions, assembly instructions, and drawings of all hardware.

KEY WORDS

Corrugated Panels
Space Shuttle
Thermal Protection System
Titanium Panels
Metallic Reradiative Panels

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1.0 INTRODUCTION

This document contains all of the data required for submittal under Contract NAS 1-11154, "Structural Evaluation of Candidate Space Shuttle Thermal Protection Systems". Included are design requirements, structural data, instrumentation data, recommended test conditions, assembly instructions, and drawings of all hardware.

For several years The Boeing Company has conducted design and analysis studies of the Space Shuttle vehicle. Following submittal of the Phase B proposal, the company continued on an IR&D program to investigate critical Space Shuttle design problems. One of the areas selected for extensive study was the external thermal protection system. Consequently, a Boeing funded IR&D program was established to design, analyze, fabricate, and test metallic reradiative TPS panels. The panel design from this program selected for this proposal is shown in Figure 1-1. This panel has a length of 31" and a wide of 15" as shown in the figure.

The TPS panel design uses 6Al-2Sn-4Zr-2Mo titanium alloy which provides high temperature capability to 1000°F. This titanium alloy and design were selected because studies indicate that large areas of both the orbiter and booster (approximately 30 to 50% of the wetted surface) would be adequately protected by this TPS. The proposed design is also much lighter than panels made of other material in this use range. Further, the titanium TPS program filled a gap in Space Shuttle research apparently not being worked by others in NASA or industry.

Confidence in the design has been obtained by extensive thermal, stress and dynamics analyses, material properties testing, thermal cycling of the basic panel

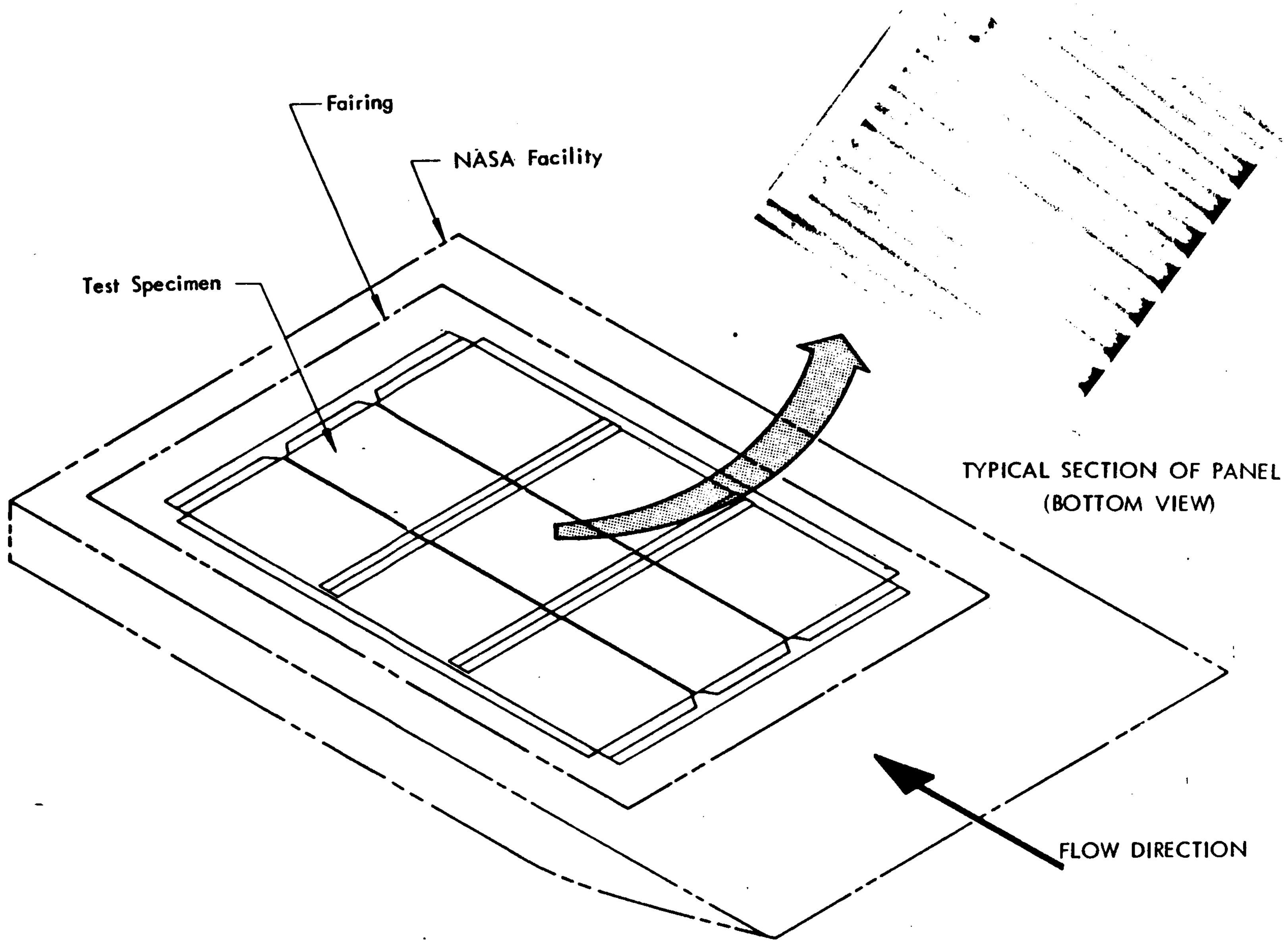


Figure 1-1: TPS PANEL ARRANGEMENT

section including hot salt exposure, and development of solutions to all of the fabrication problems. This design is a logical extension of TPS technology developed on both the X-20 and SST programs. All fasteners are readily accessible at the panel exterior surface for ease in installation and removal. A conscious effort has been made to minimize attachments and allow independent removal of any one panel. Realistic joint and panel attachments representative of flight hardware to withstand heating, loading and acoustic conditions are used.

2.0 DESIGN REQUIREMENTS

2.1 Design Criteria

The TPS panel was designed in accordance with the structural design criteria of Reference 1 , pertaining to load definition, factors of safety, allowable mechanical properties, service life, material design thickness, selected natural and man-made environments as specified under Design Environment, Section 2.2. The following applicable criteria were used:

a) Factors of Safety

Load Condition	Factor of Safety	
	Yield	Ultimate
Pressure	1.0	1.5
Thermal	1.0	1.0

b) Deflection

Item	Span ÷ Deflection
Overall Panel	100
Local Panel (Skin)	15

c) Service Life - 100 Missions

d) Skin Panel Flutter

The panel shall be free of flutter at all dynamic pressures up to 1.5 times the local dynamic pressure expected to be encountered at any Mach number during normal flight in accordance with Reference 1 .

e) Thermal Design

An uncertainty factor of 1.25 on turbulent flow heating rates was used. No free edge forward facing steps are allowed and all forward facing discontinuities shall be minimized (for upper surface panels, protruding head fasteners are allowed).

2.2 Design Environment

The titanium panel was designed to withstand the aerodynamic heating, skin friction, normal pressure, vibration, and acoustic noise occurring under all flight design conditions for a typical Space Shuttle booster, since this represents the highest pressure environment. In addition, the panel was designed to be free of panel flutter.

Trajectory

The trajectory parameters used for design of the panel are shown in Figure 2-1. They are representative of a typical booster configuration.

Thermal

The design heating rate and panel equilibrium temperatures resulting from the foregoing trajectory are shown in Figure 2-2. The panel has been designed for a peak temperature of 1000°F. For a given peak temperature, the temperature profile shown is relatively insensitive to staging conditions, booster configuration, and platform loading. Consequently, the temperature profile shown represents that expected for a typical booster.

Pressure

Figure 2-3 shows the pressure differential used for design of the panel. The maximum positive pressure of 2.50 psi occurs during reentry. This pressure is a conservative estimate of the pressure occurring on the side of the body at this time. The maximum negative pressure of -2.43 psi occurs during a subsonic

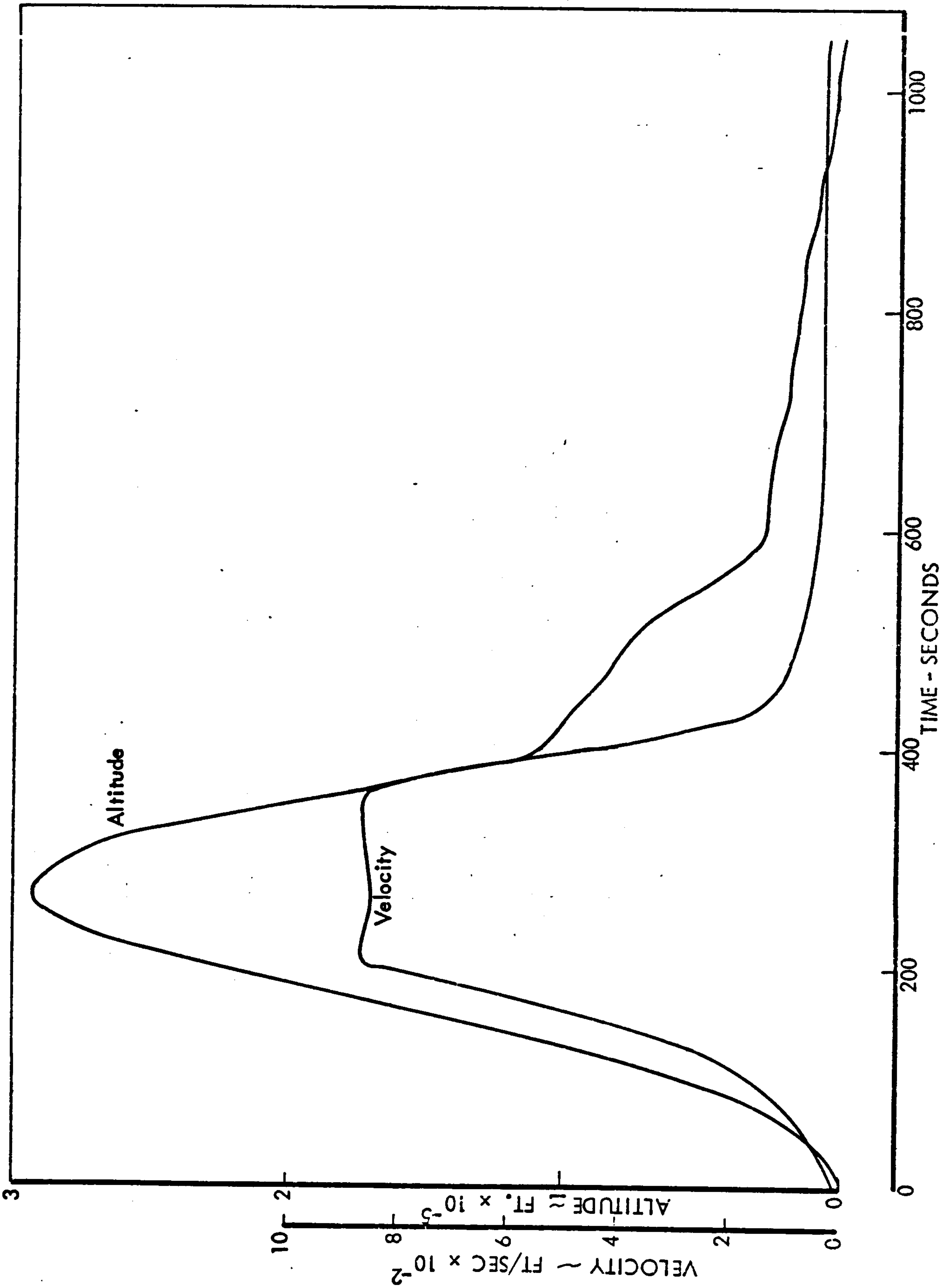


Figure 2-1: DESIGN TRAJECTORY DATA

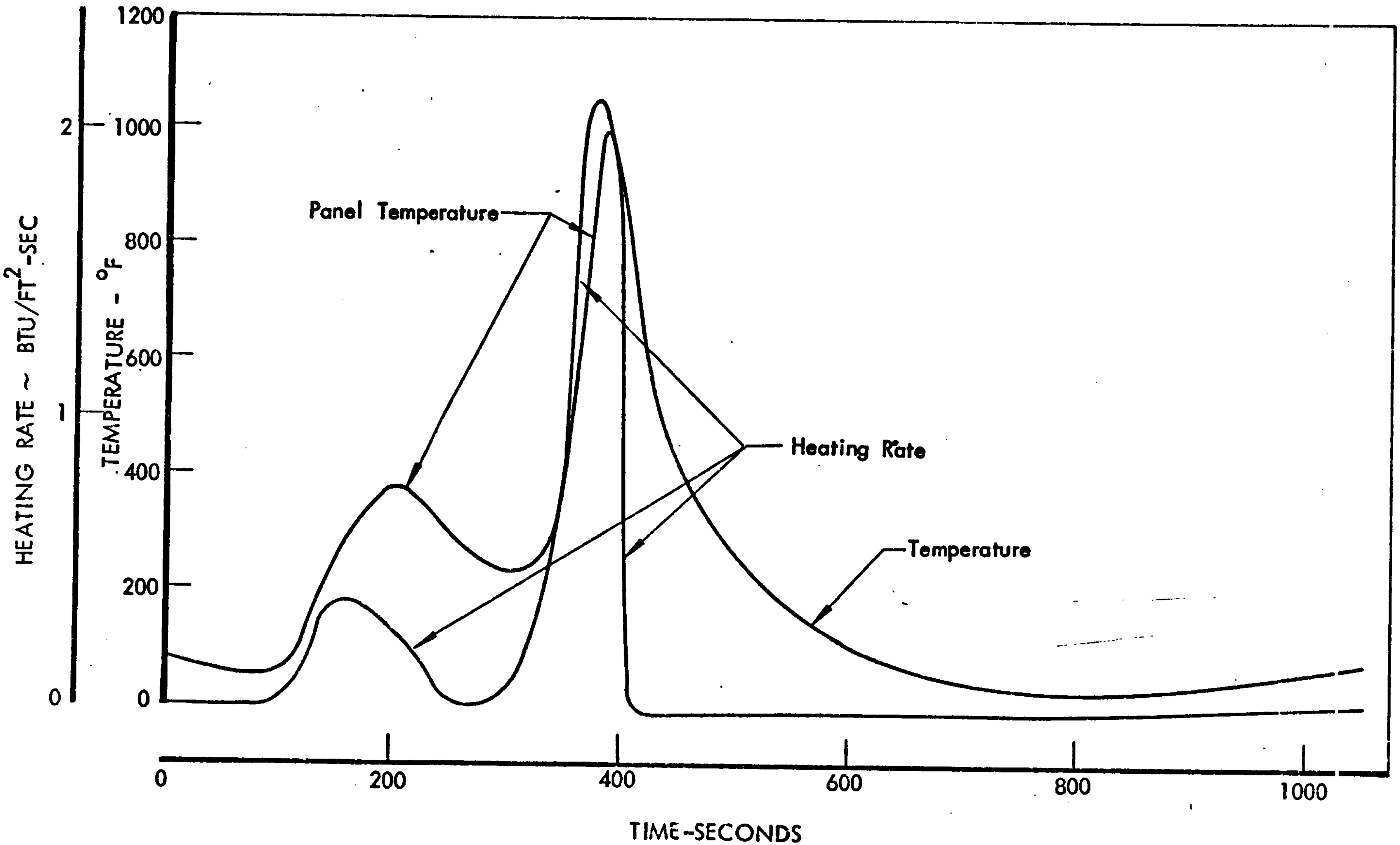


Figure 2-2: DESIGN HEATING RATE AND TEMPERATURE

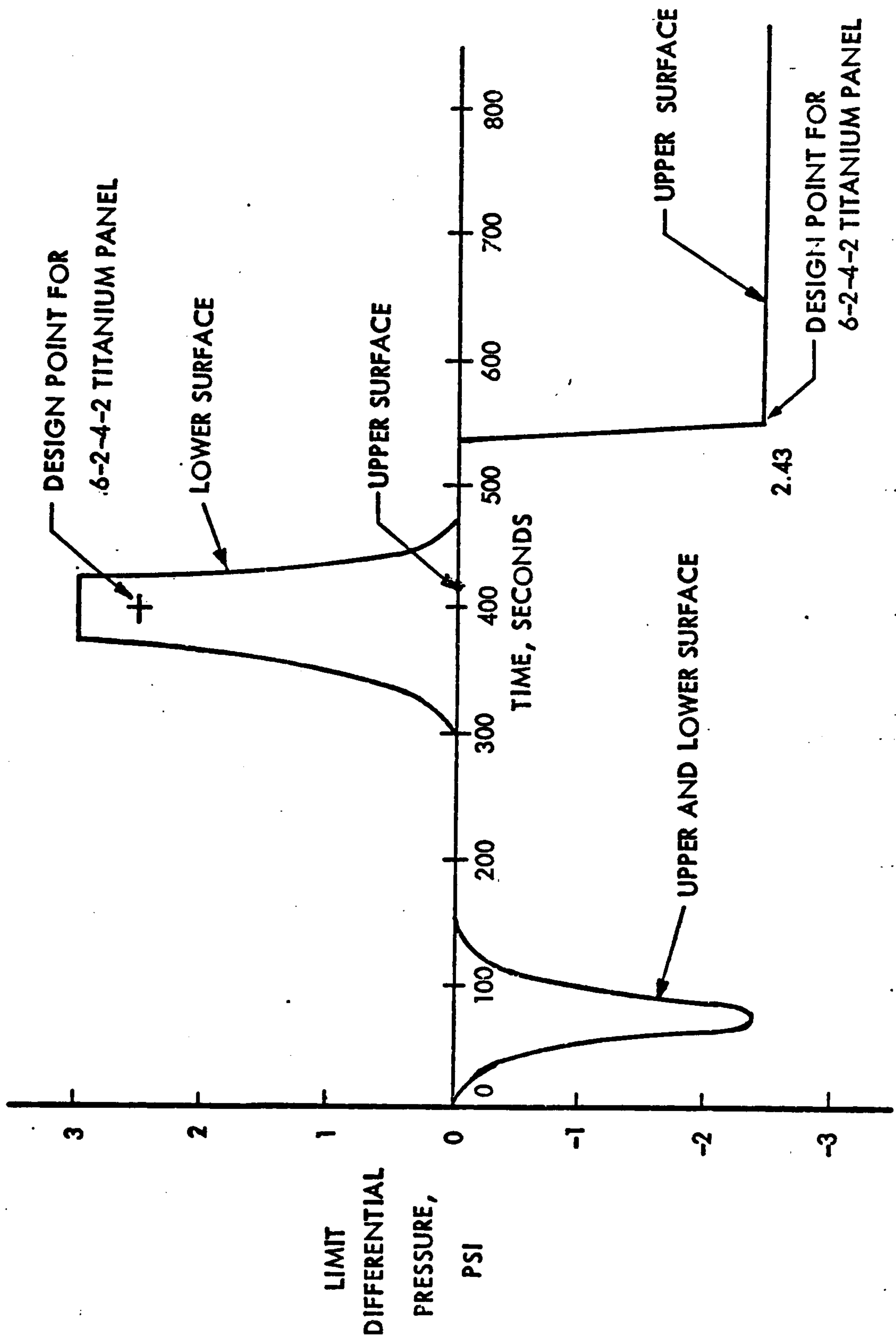
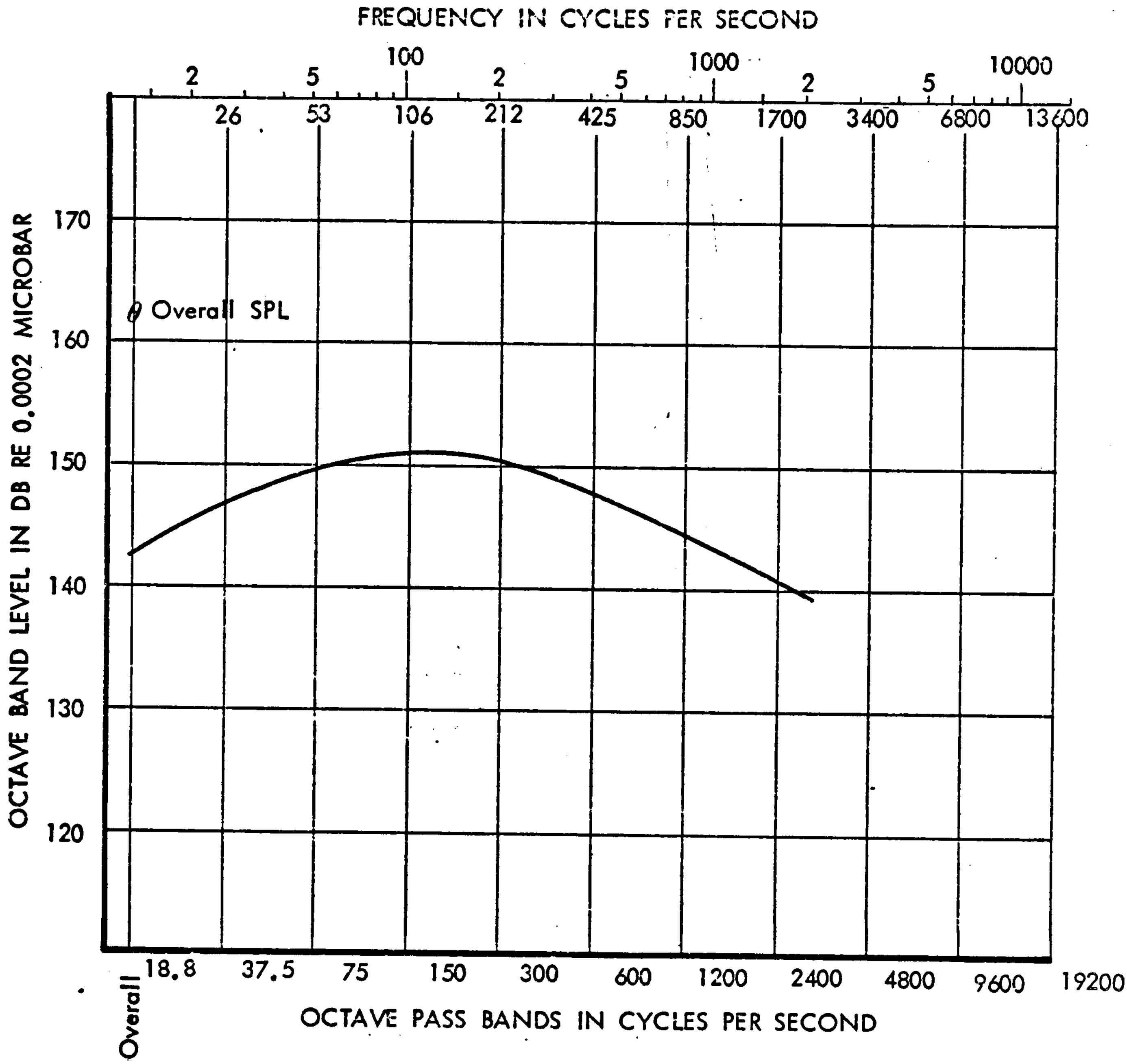


Figure 2-3: DESIGN DIFFERENTIAL PRESSURE

maneuver subsequent to reentry. It is the pressure occurring on the upper surface of the booster wing at a location near the leading edge. Pressures resulting from wind shear conditions during boost are approximately equal to subsonic maneuver conditions. Consequently, the conditions used for design are representative of the critical pressures and temperatures expected for a typical booster.

Acoustic

The acoustic design environment considered for the panels is shown in Figure 2-4. Analysis of the configuration shows the frequency content expected with 12 engines, 30 foot exhaust deflector separation, and 550,000 lb/engine thrust.



550,000 Lb/Engine Thrust
12 Engines
30 Ft. Deflector Separation
Sound Level At Vehicle Centerline 48 Ft Forward Of Nozzle Exit Plane

Figure 2-4: ACOUSTIC ENVIRONMENTAL REQUIREMENT

3.0 STRUCTURAL DATA

3.1 Material Properties

The material properties used for design of the TPS panels are summarized in Figure 3-1.

3.2 Analyses

3.2.1 Thermal Analysis

In order to assure the thermal structural integrity of the titanium TPS panel shown in Figure 7-1, a thermal analysis was made considering that such a panel could be located on the upper or side of the body, or the upper side of the wing of an orbiter or booster. A typical booster configuration was selected and the heating rates determined using the Boeing Rho-mu heat transfer prediction method (Reference 2) with trajectory parameters such as shown in Figure 2-1. Having obtained representative heating rates, as shown in Figure 2-2, which contain a factor of 1.25 to account for uncertainties in predicting turbulent flow, the temperature distributions through the panel were calculated in order to identify the temperature gradients required for determining panel thermal stresses. The peak panel service temperature was limited to 1000°F. The temperature distributions were obtained using the Boeing Thermal Analyzer Program (Reference 3) for the panel model shown in Figure 3-5. This model is representative of the TPS panel edge strip approximately 3.8" wide where supporting edge member "Z" section, corrugation and face sheet meet and form a junction. The model shown is three dimensional and the analysis accounts for conduction and internal natural convection. It was shown that the heat transfer due to internal convection was

Material	Titanium 6Al-2Sn-4Zr.-2 Mo	Inconel 718
Specification	MIL-T-9046	AMS 5596
Physical Properties:		
Density, lb./in.^{3}	0.164	0.296
Specific Heat, Btu/lb. - °F	Figure 3-2	Figure 3-2
Conductivity, Btu-in/ft^2-Sec-°F	Figure 3-2	Figure 3-2
Emittance	0.500	0.800
Absorptance	0.500	0.800
Thermal Expansion in./in./°F	Figure 3-2	Figure 3-2
Mechanical Properties:		
Strength	Figure 3-3	Figure 3-4
Poisson's Ratio	0.32	0.29

Figure 3-1: TPS PANEL MATERIAL PROPERTIES

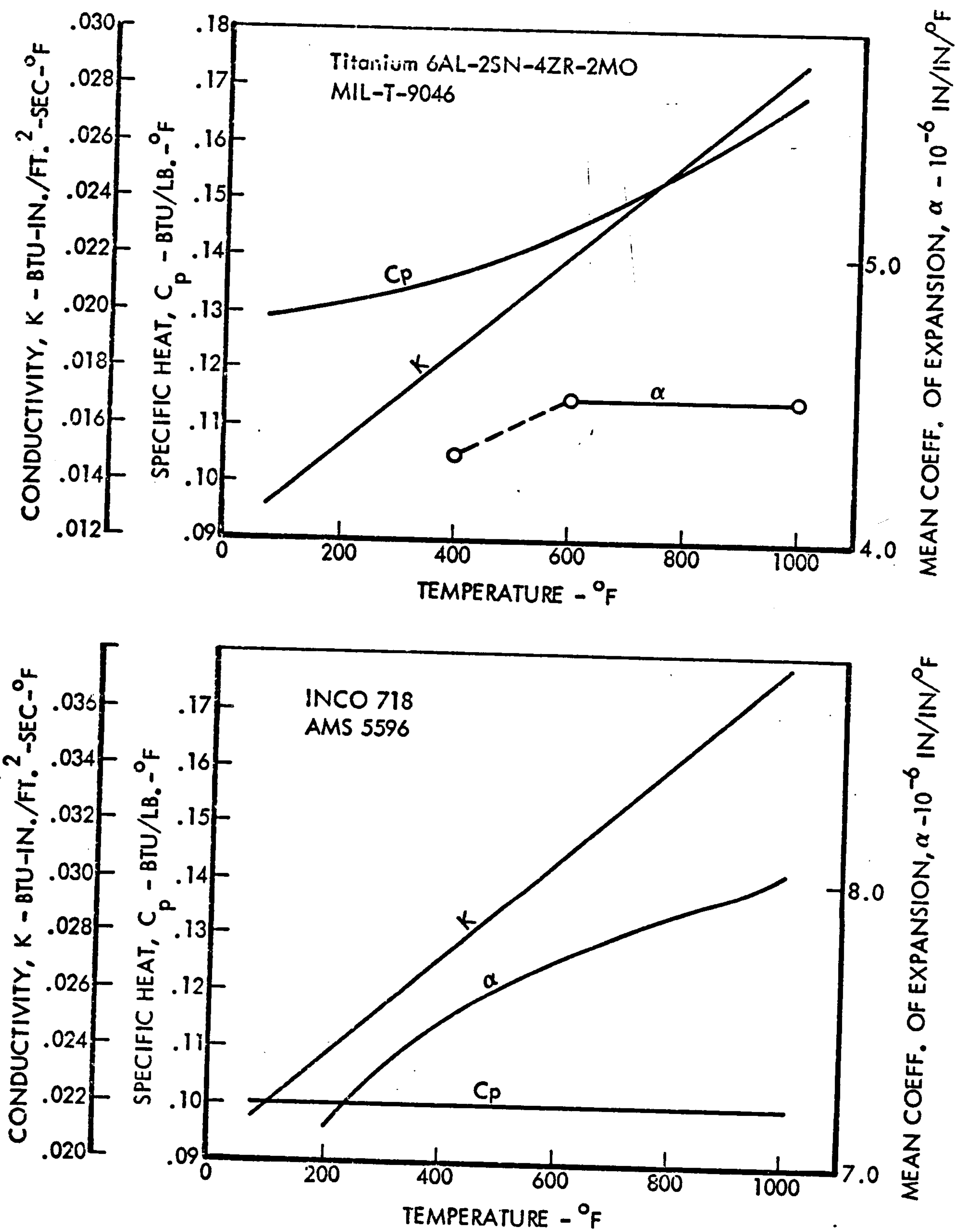


Figure 3-2: TPS PANEL MATERIAL PHYSICAL PROPERTIES

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65?-2414

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Ron Torgason

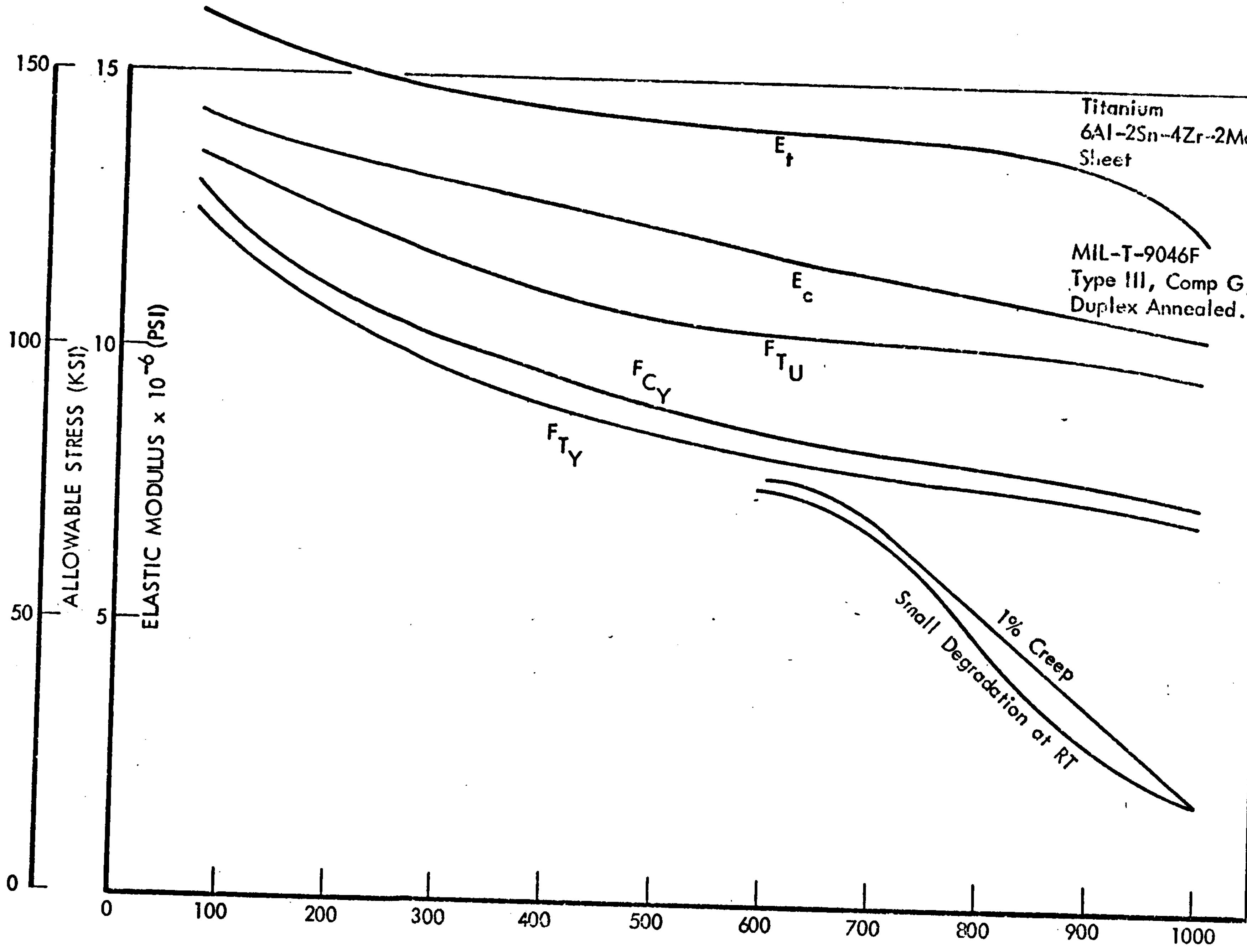


Figure 3-3: TITANIUM 6Al-2Sn-4Zr-2Mo MECHANICAL PROPERTIES

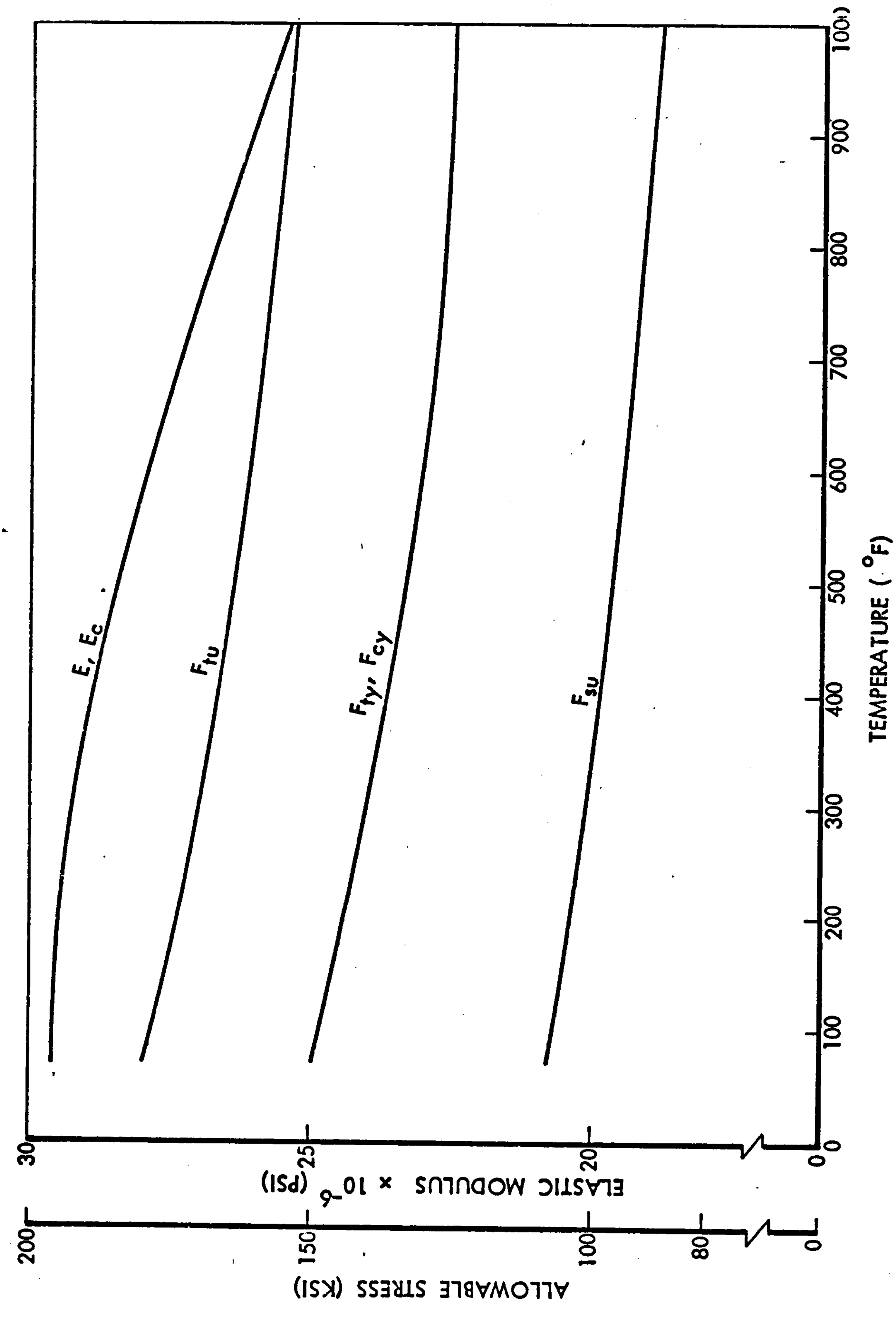


Figure 3-4: INCONEL 718 MECHANICAL PROPERTIES

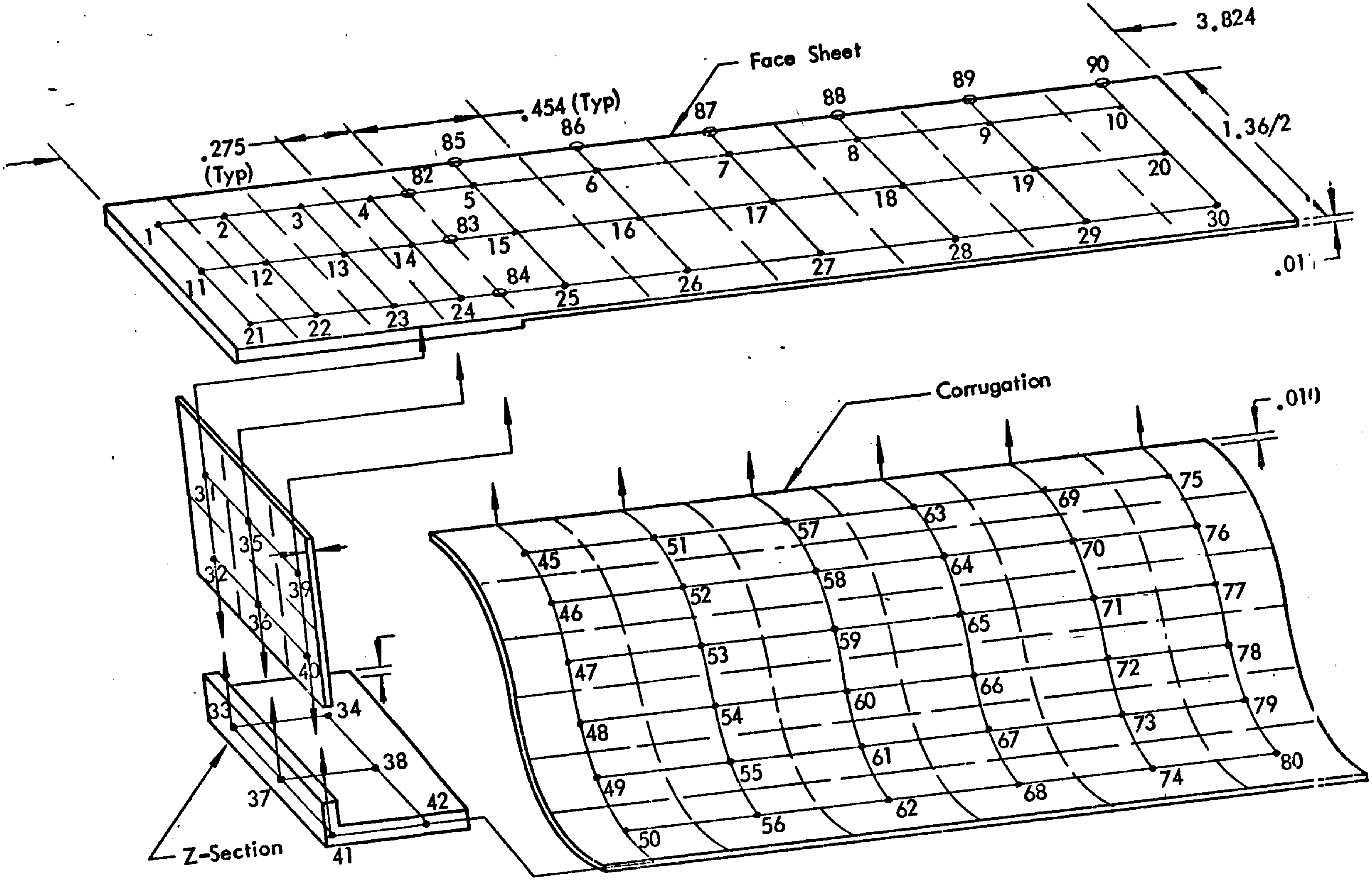


Figure 3-5: THERMAL ANALYZER MODEL

negligible. The results of this analysis are shown in Figures 3-6 and 3-7.

Since internal radiation exchange was not included because of the high complexity of the 3 dimensional model, the obtained temperature gradients will result in conservative stresses. In order to assess the influence of radiation in reducing the temperature gradients, a two-dimensional model was used as shown in Figure 3-8. The results of this analysis are shown in Figure 3-9. It can be seen that at the maximum temperature of 1000°F the temperature gradient is reduced by approximately 200°F. In the lower surface temperature regime at the structural junction (Figure 3-5 and 3-6) toward the edge of the panel (see Node 11) this reduction will be smaller and therefore no excessive conservatism in thermal stress determination should be expected.

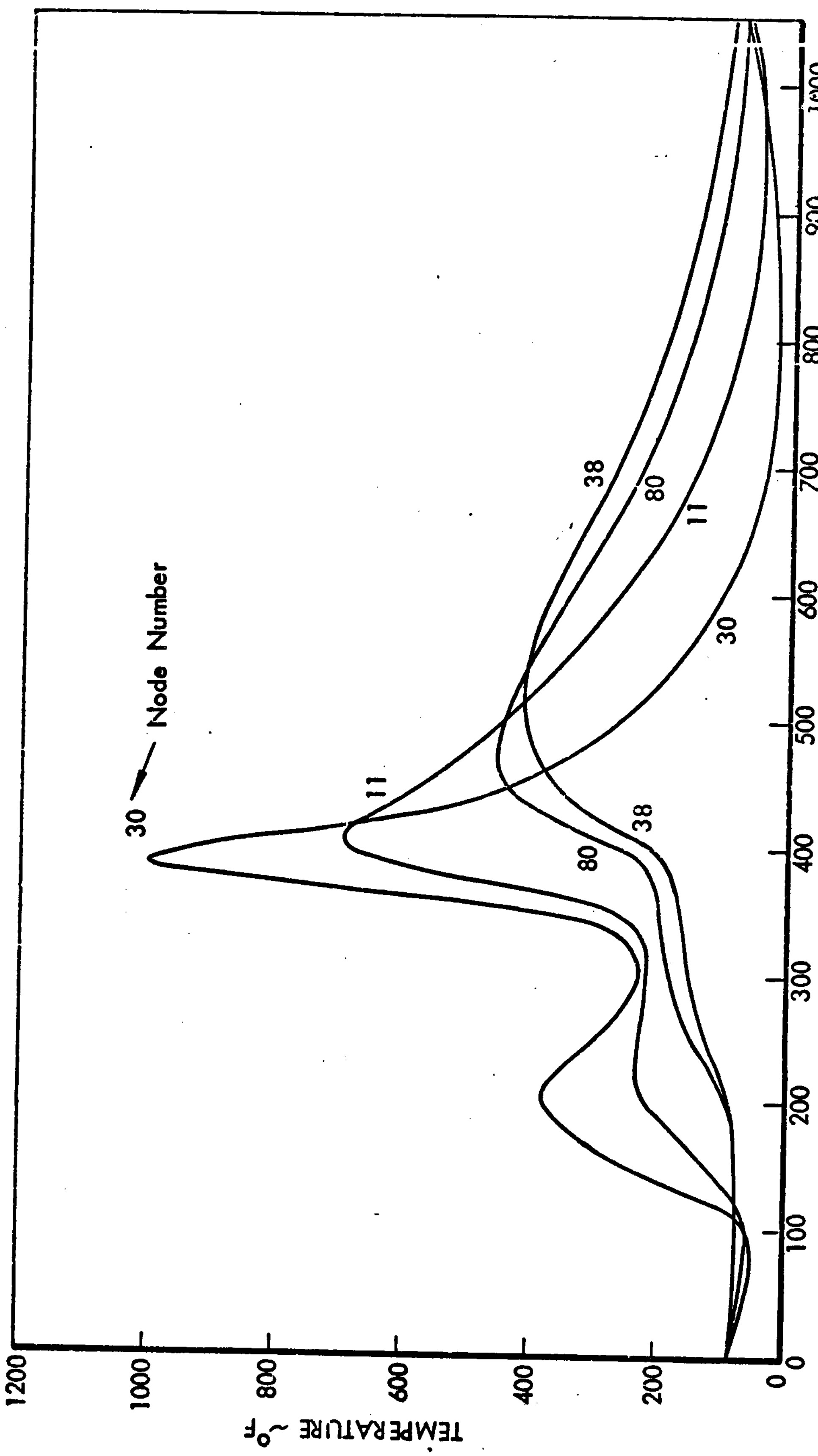


Figure 3-6: TITANIUM TPS PANEL - TEMPERATURE DISTRIBUTIONS

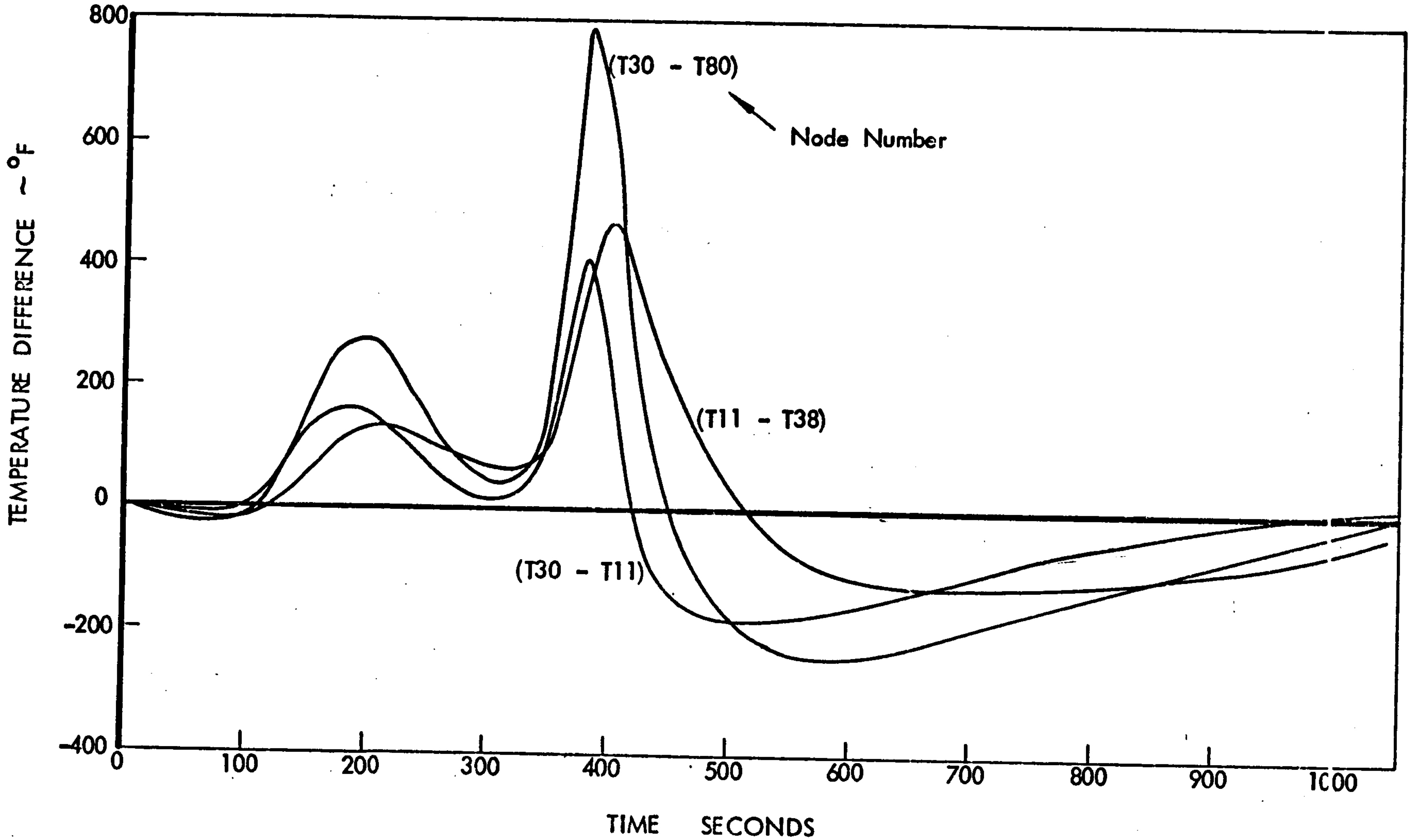


Figure 3-7: TITANIUM TPS PANEL TEMPERATURE DIFFERENCES

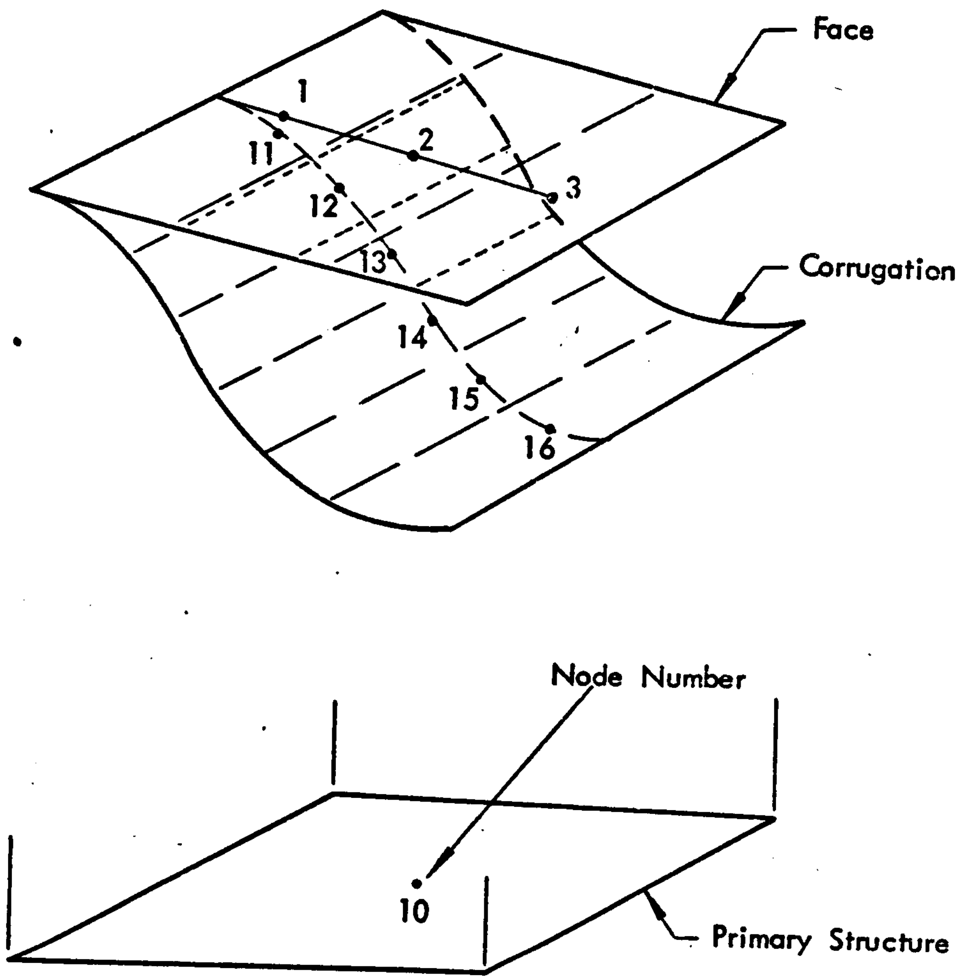


Figure 3-8: TITANIUM TPS 2-D MODEL, INTERNAL RADIATION, $\varepsilon = .50$
INTERNAL CONVECTION INCLUDED

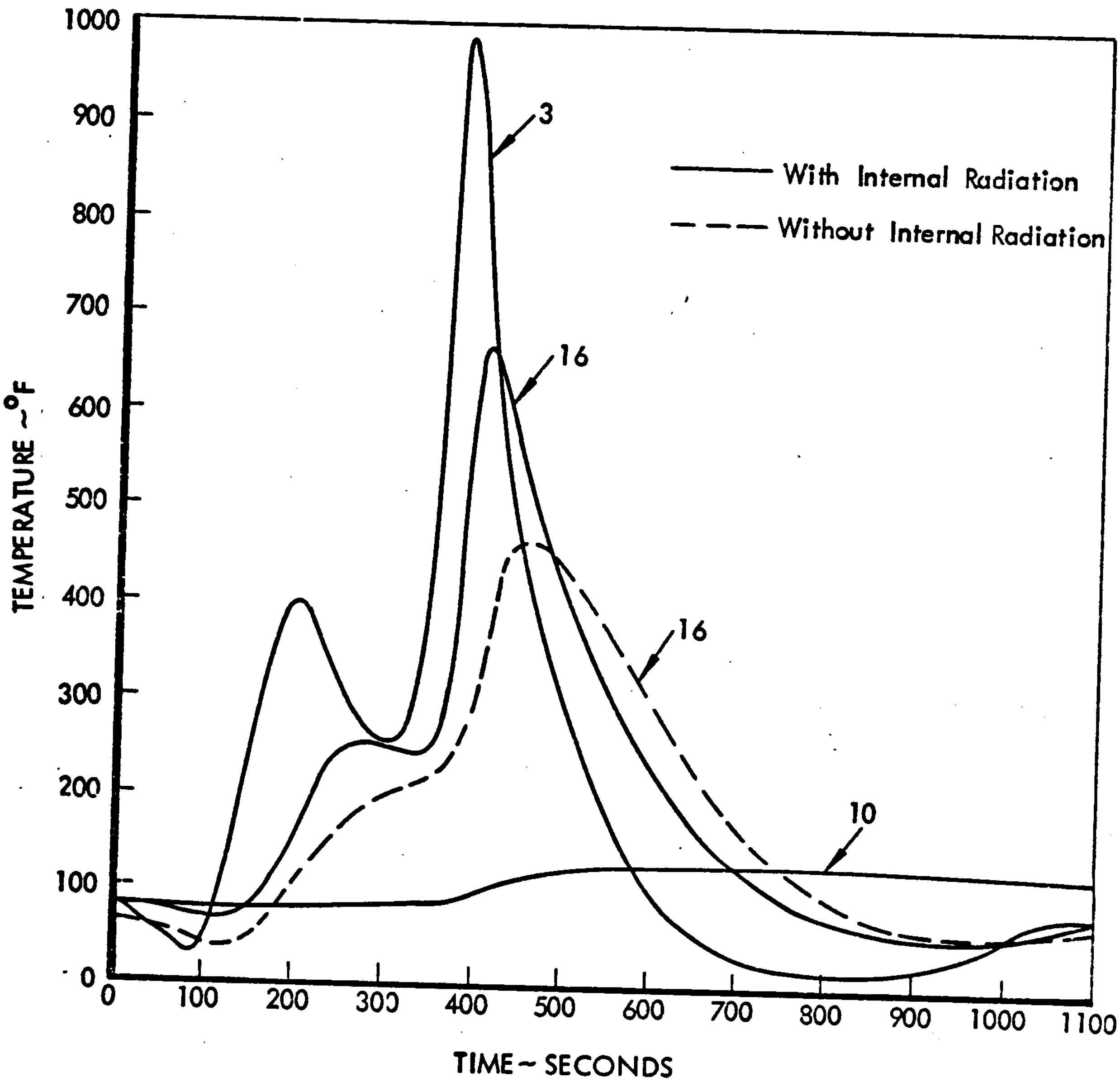


Figure 3-9: TWO DIMENSIONAL TEMPERATURE DISTRIBUTIONS (NOT INFLUENCED BY PANEL EDGE EFFECTS)

3.2.2 Stress Analysis

A finite element static structural analysis of the titanium TPS panel was performed for two design loading conditions. The Boeing Company's ASTRA (Advanced Structural Analyzer) computer program based on the direct stiffness displacement approach to the finite element method was used. The finite element model is shown in Figure 3-10. The finite element model consisted of one quarter of the panel supported at the corner by a "Z" clip. Symmetrical boundary conditions were enforced along the panel center-lines. The model contains 131 nodes with 739 degrees of freedom. 140 finite elements were used in the model. The upper skin was modeled using 80 isotropic quadrilateral plates with 50% effective area. The corrugation was modeled using orthotropic quadi-lateral plates to duplicate the stiffness of the actual circular arc corrugations. The "Z" clip was modeled using three general beams with 6 degrees of freedom per node. Gussets on each side of the "Z" clip are modeled using triangular isotropic plates. Figures 3-3 and 3-4 show the material properties used for the panel analysis. The model is an excellent representation of structural stiffness, but provides only approximate stresses in the corrugation or edge member, due to coarseness of the elements in these areas. Hand analysis was also performed for these details.

Solutions of static stresses and deflections due to airloads and thermal effects were obtained. Figures 3-10 and 3-11 show the temperature distribution at each node used in the analysis for the two design conditions analyzed. These temperature distributions are the result of a thermal analysis based on conduction only with radiation neglected (see Thermal Analysis). The thermal effects are therefore conservative. Two additional conditions with airload only were analyzed to determine the thermal effects present in the combined load-temperature conditions.

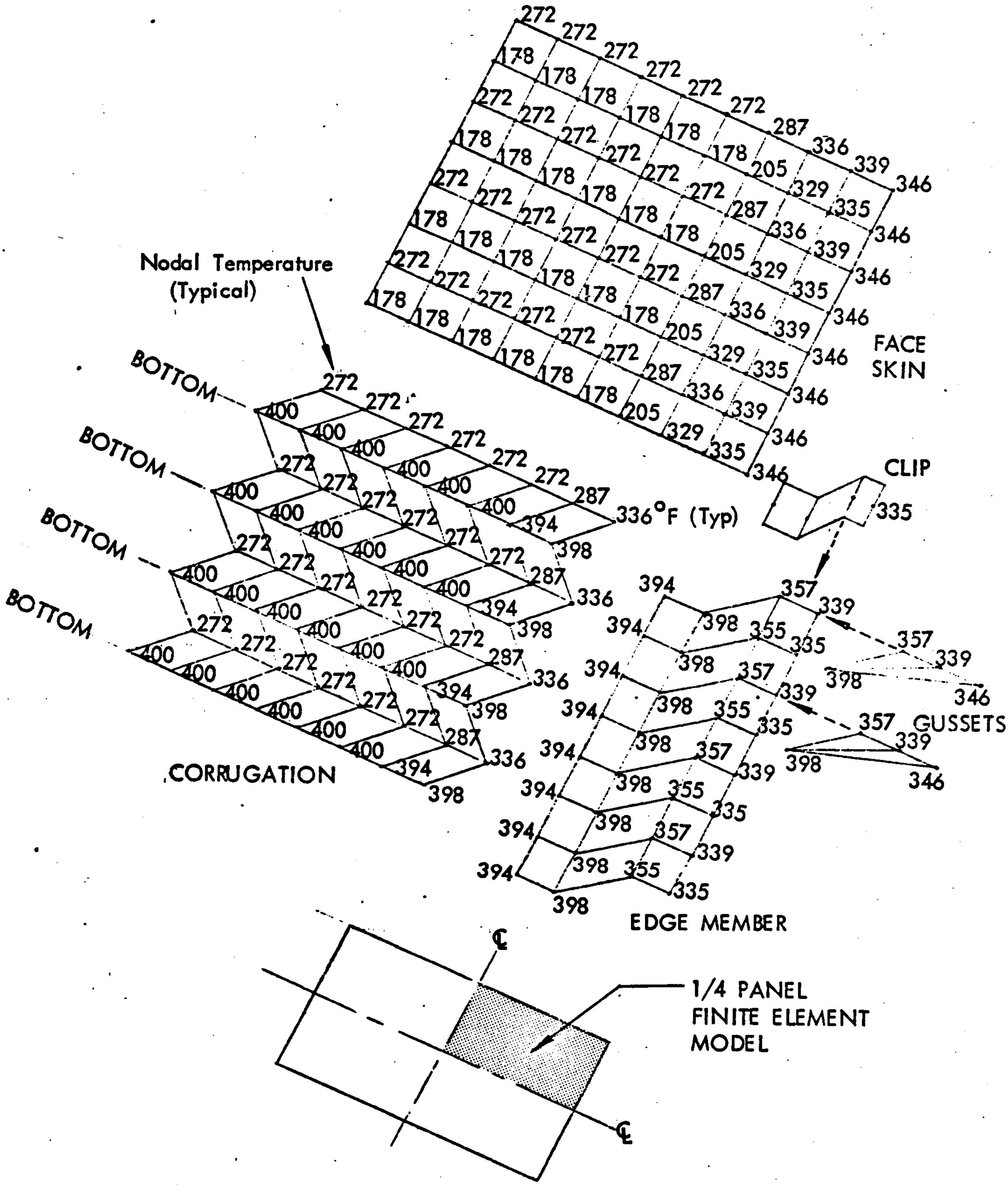


Figure 3-10: SUBPANEL FINITE ELEMENT MODEL AND NODAL TEMPERATURES FOR ULTIMATE AIRLOAD = -3.64 Psi CONDITION 1

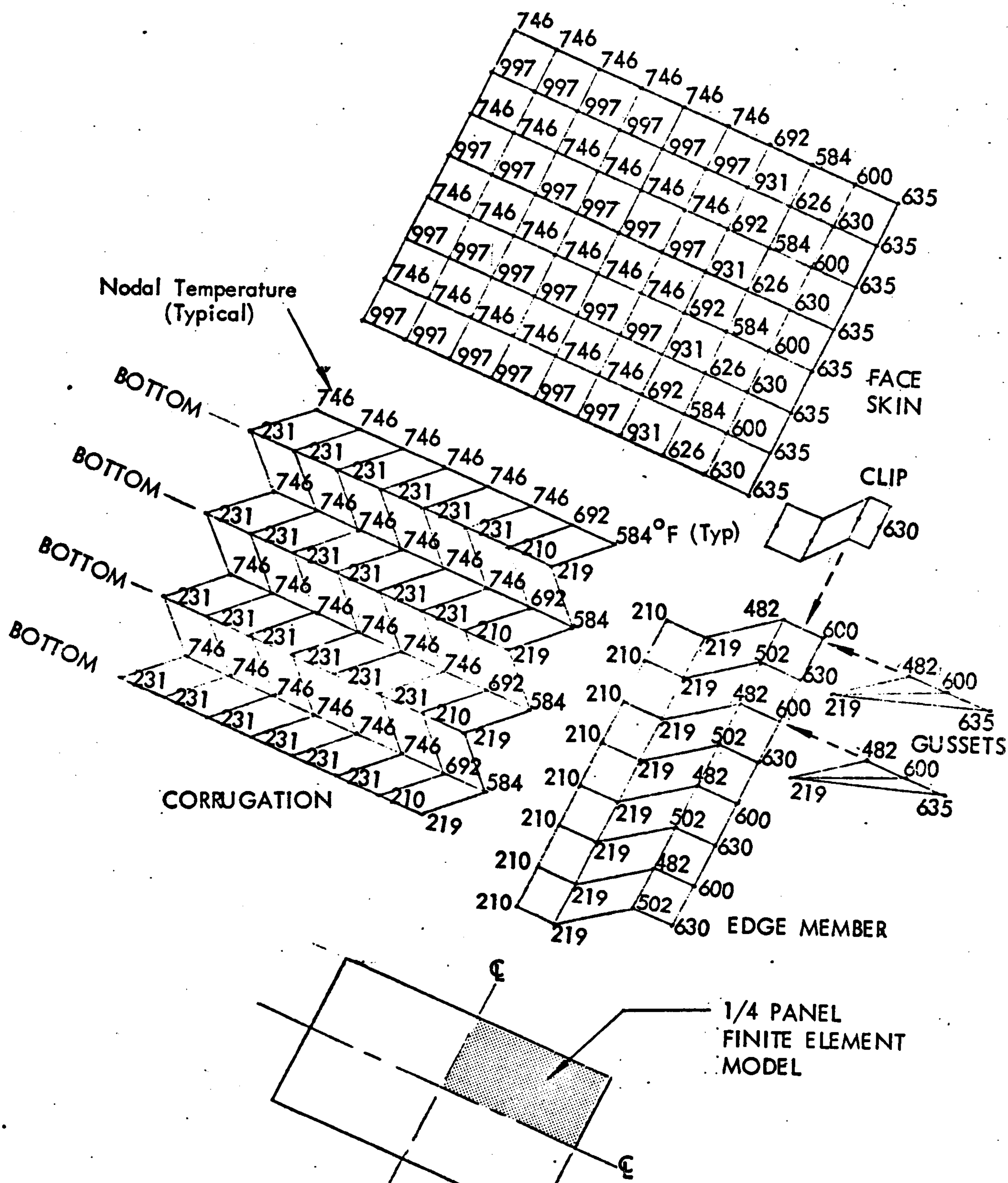


Figure 3-11: SUBPANEL FINITE ELEMENT MODEL AND NODAL TEMPERATURES FOR LIMIT AIRLOAD = 2.5 Psi CONDITION 2

Figure 3-12 shows the results of the ASTRA analysis for panel vertical deflection along the centerline of the panel. Figure 3-13 illustrates the panel vertical deflection across the width of the panel at the centerline. Figure 3-14 shows the deflection of the edge member. These deflections agree with values calculated from elementary beam theory using a summation of deflections of the edge member between "Z" clips and corrugation deflection between edge members. The thermal deflections agree with calculations for simply supported beams subjected to linear thermal gradients through the beam depth. The ASTRA analysis shows a vertical deflection of the "Z" clips with respect to the edge member due to airload of -.0068 x pressure (inches). This gives a relative stiffness of approximately 5000 Lbs/In.

Figure 3-15 shows the results of the ASTRA analysis for panel stresses. The stresses at the bottom of the corrugation were extrapolated from the values of the quadrilateral plate stresses and can only be considered approximate. The upper face skin and bottom of the corrugation show higher stresses along the edges of the panel. This is caused by the edge member deflection and thermal deflection. The upper skin shows significant longitudinal thermal stresses between the corrugations. These stresses are caused by the differences in temperature of the skin and corrugation. Figure 3-16 shows the skin transverse stresses at the edge member. Significant transverse thermal stresses in the skin are also indicated. These stresses are caused by the difference in temperature between the edge member and skin, and also include full Poisson's stresses of .30 x longitudinal stress. Since these stresses are large enough to cause skin buckling, the Poisson stresses should be omitted.

Figure 3-17 shows the spanwise distribution of the transverse skin stress. This illustrates that the stresses are larger near the edge member where the thermal growth of the skin and corrugation are restrained by the edge member.

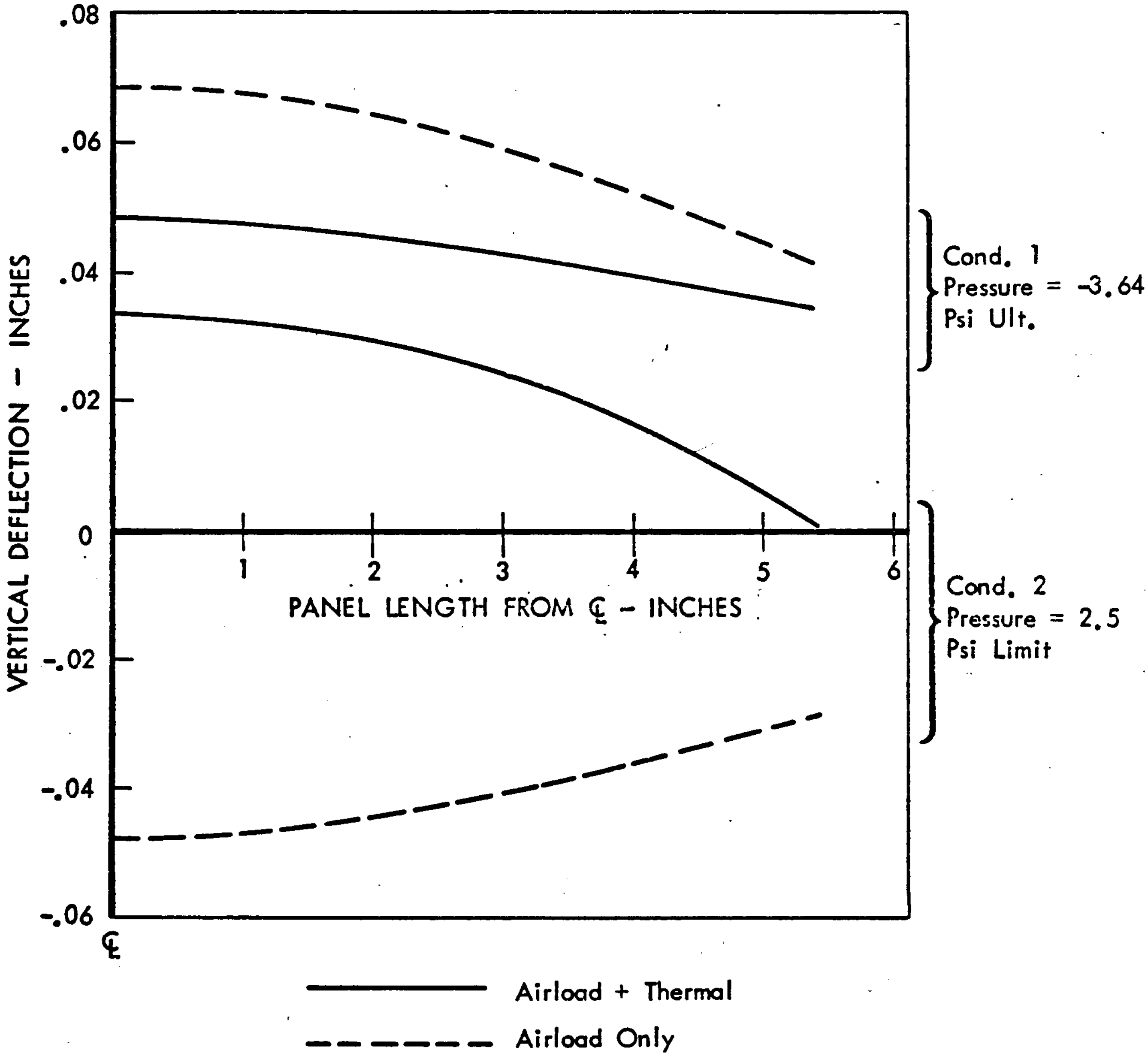


Figure 3-12: PANEL CENTERLINE DEFLECTION - FINITE ELEMENT ASTRA ANALYSIS

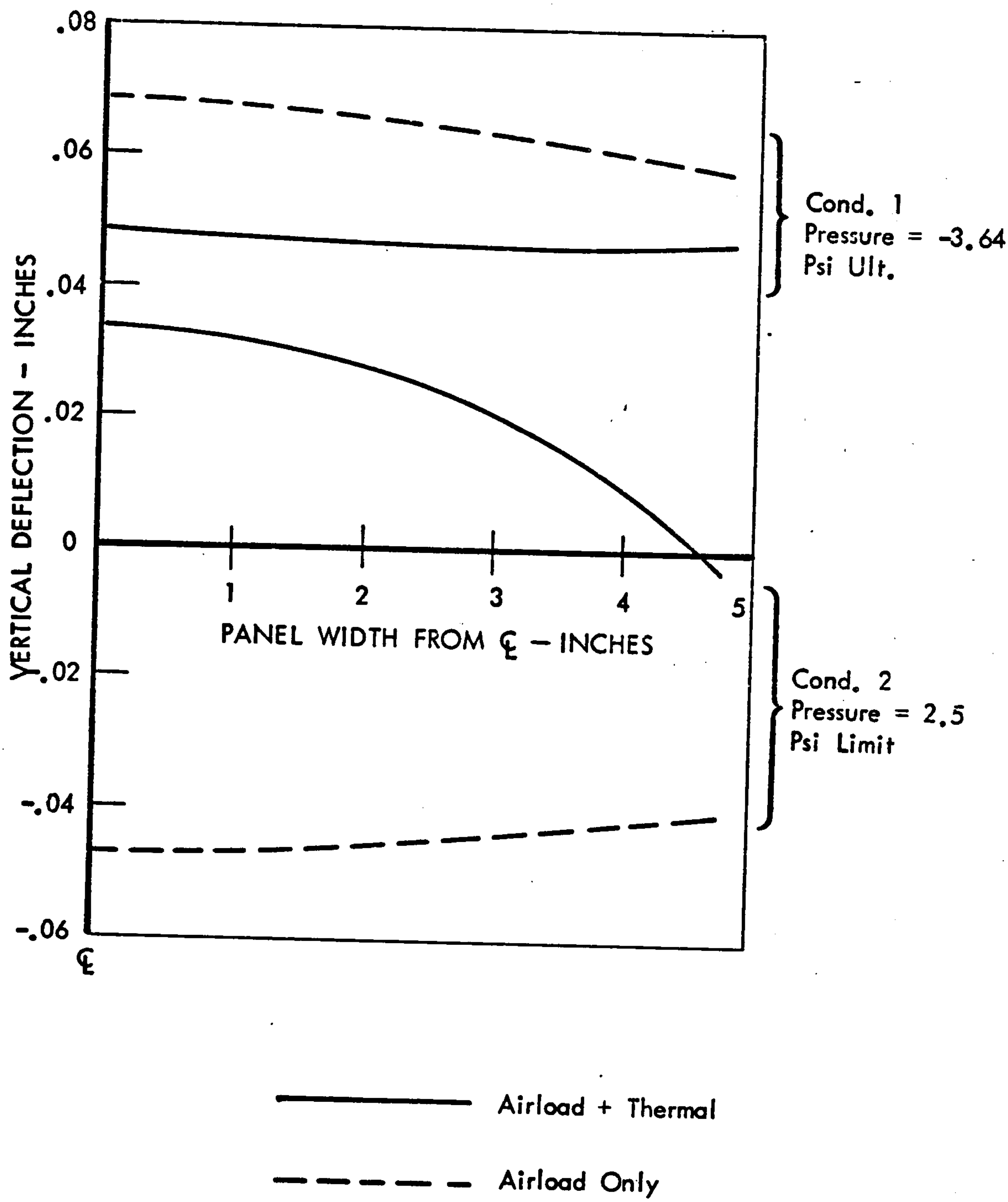


Figure 3-13 PANEL CENTERLINE DEFLECTION - FINITE ELEMENT ASTRA ANALYSIS

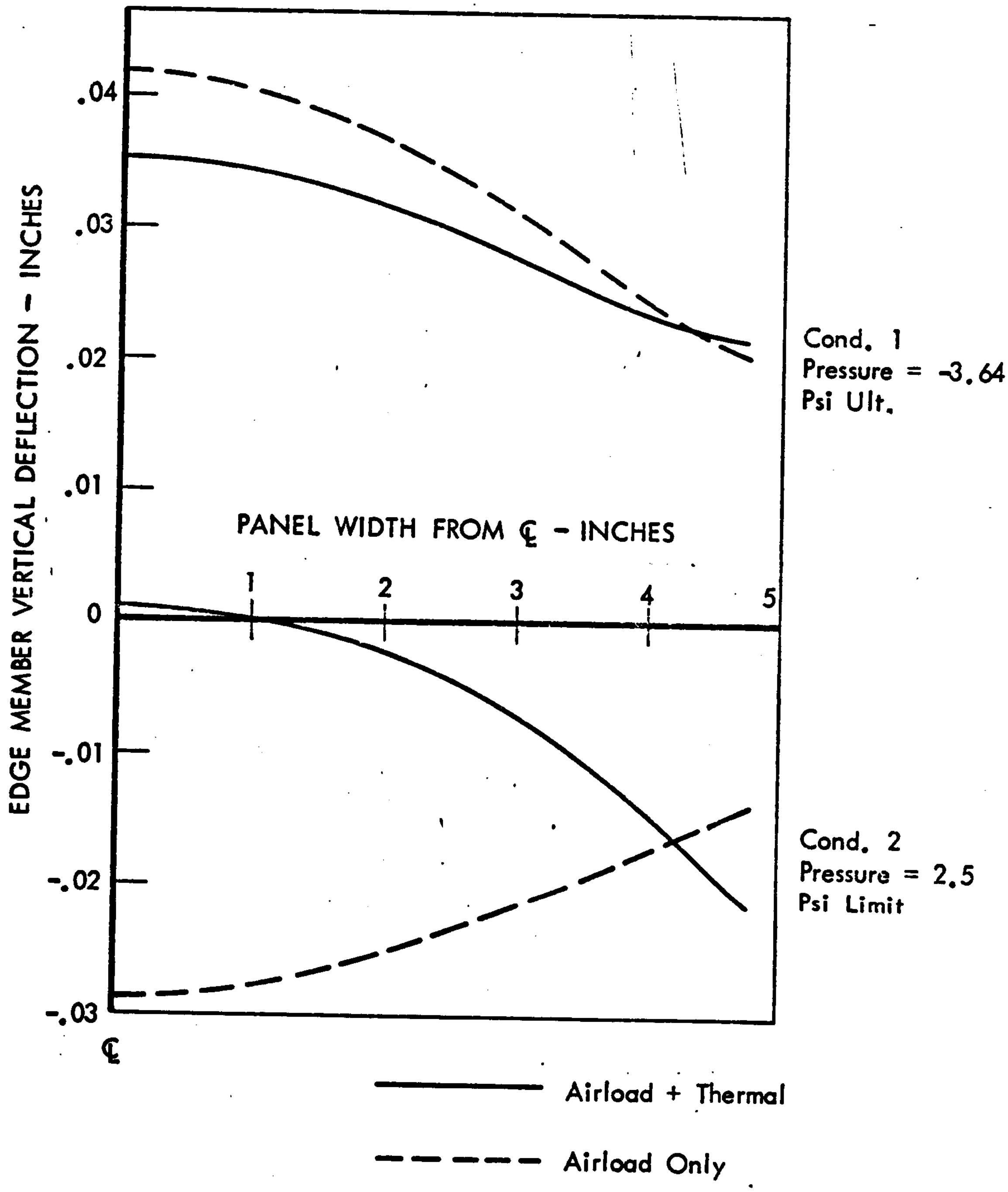


Figure 3-14: EDGE MEMBER DEFLECTION - FINITE ELEMENT ASTRA ANALYSIS

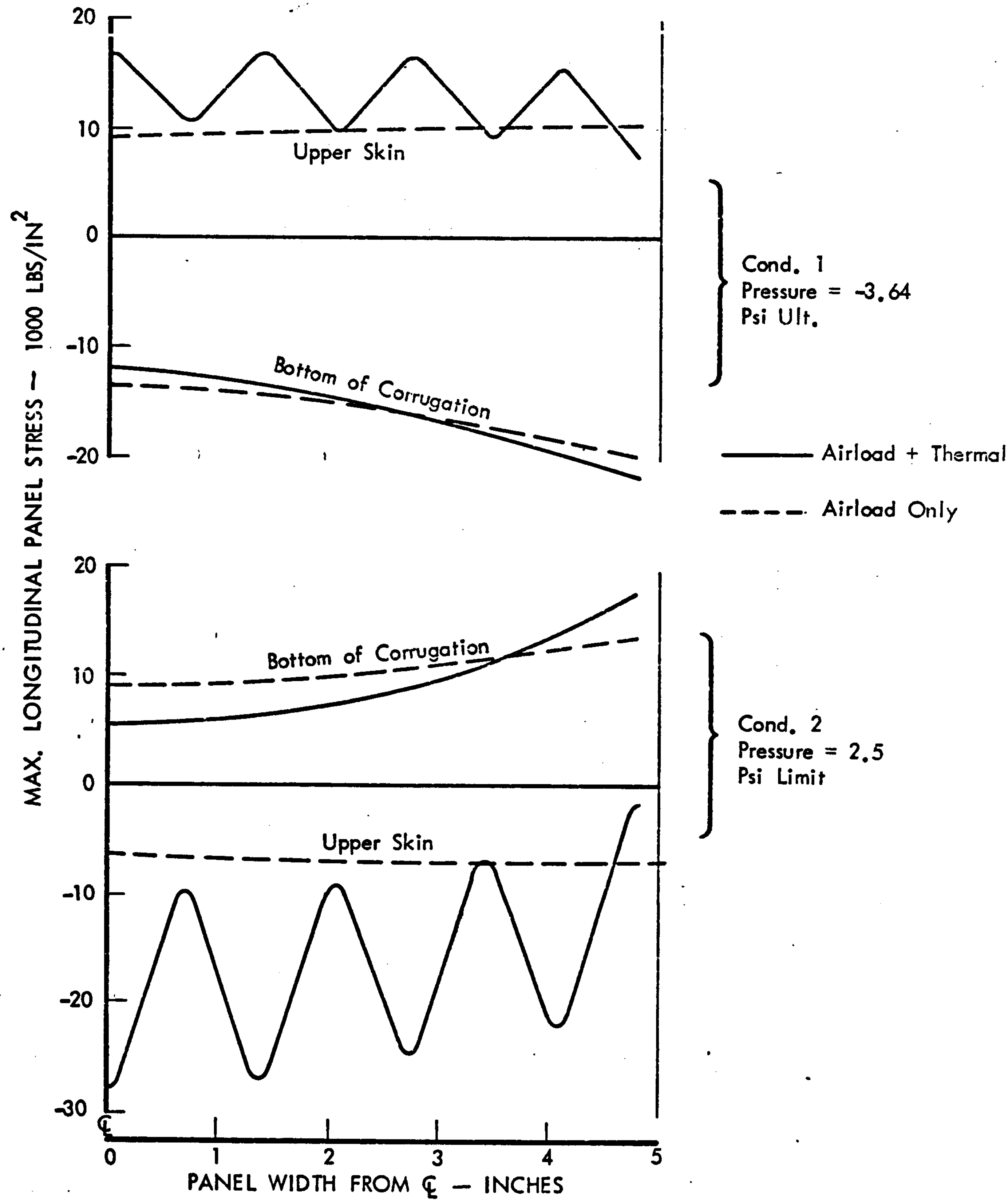


Figure 3-15: PANEL STRESSES FINITE ELEMENT ASTRA ANALYSIS

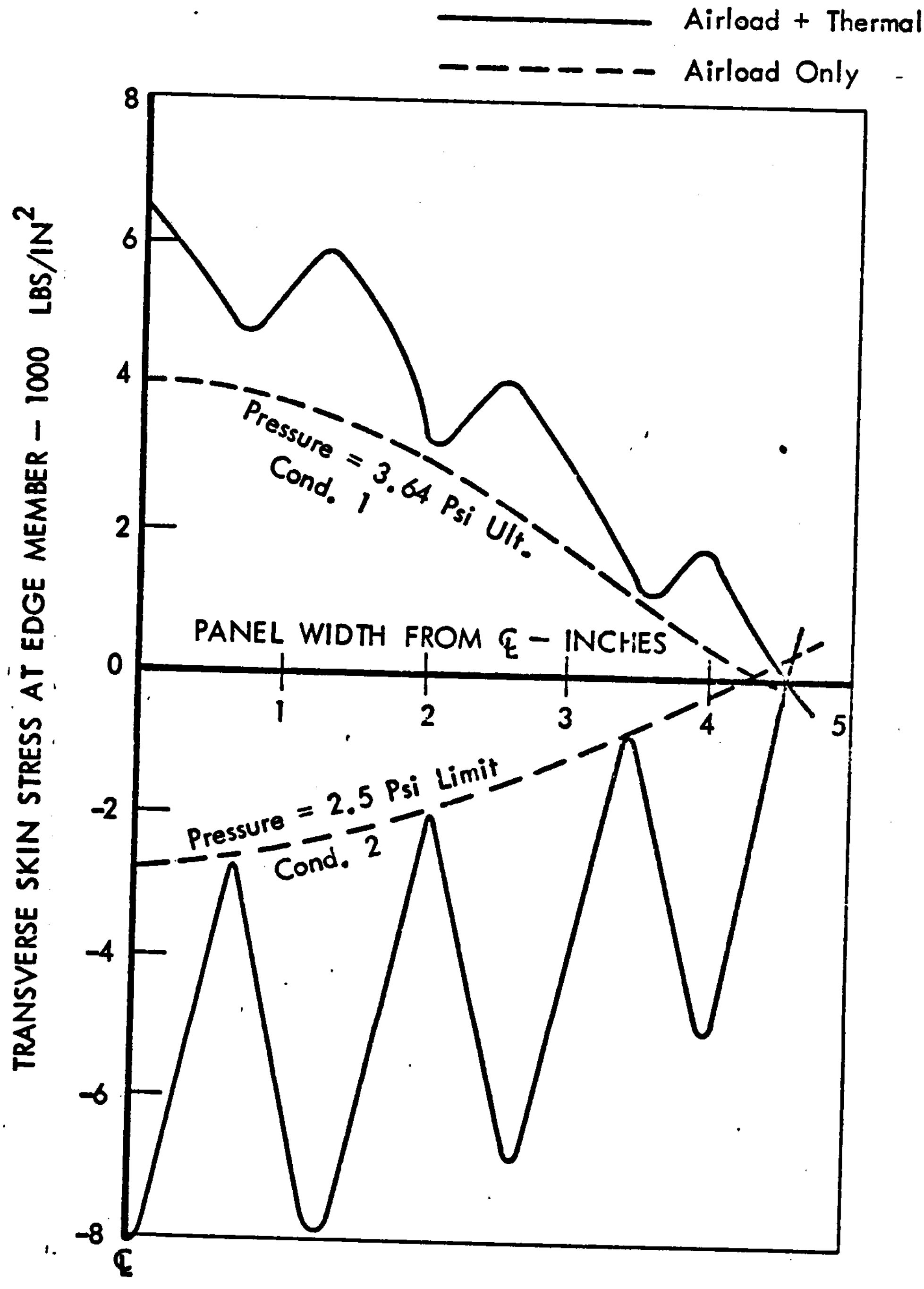


Figure 3-16: TRANSVERSE SKIN STRESS AT EDGE MEMBER FINITE ELEMENT ASTRA ANALYSIS

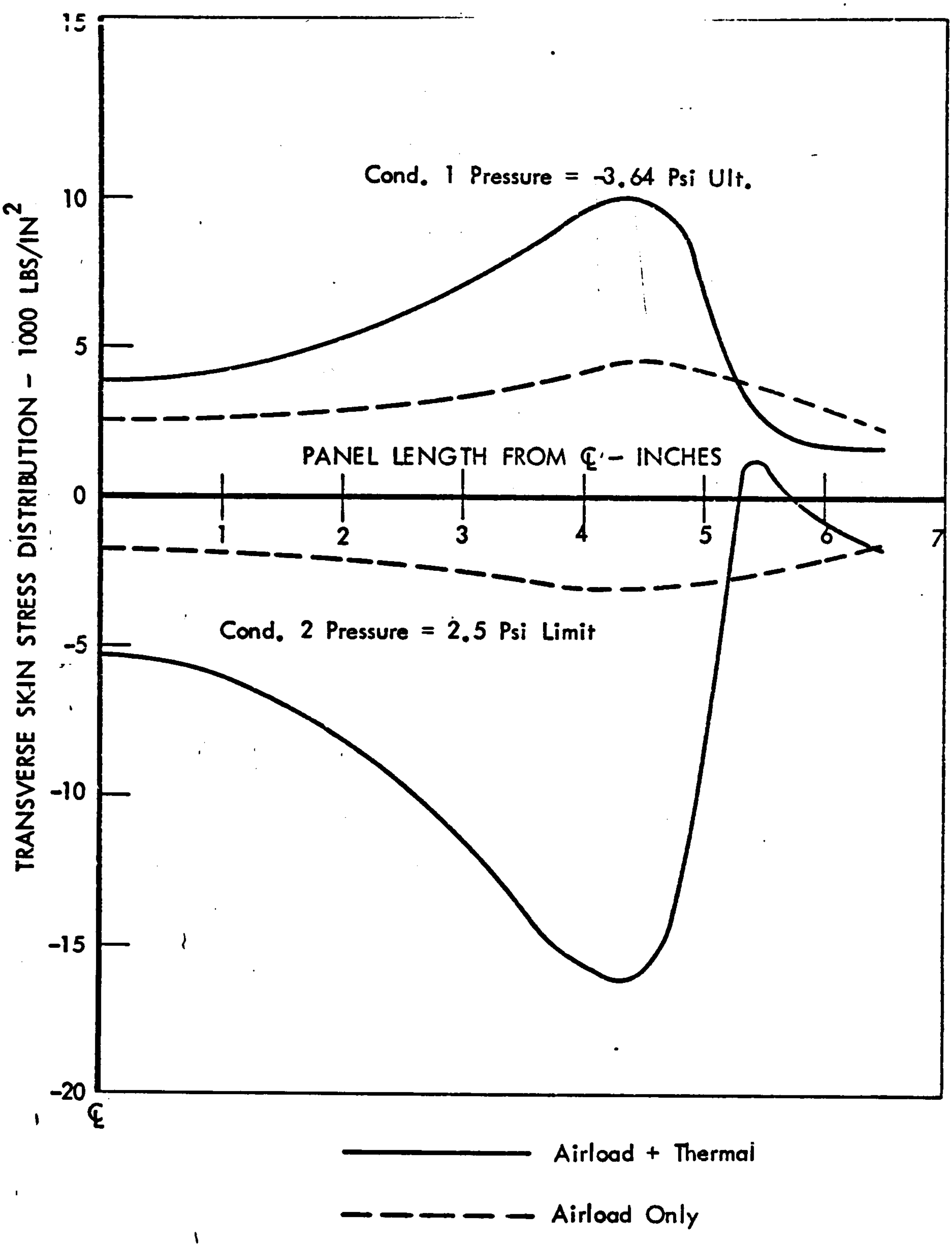


Figure 3-17: TRANSVERSE SKIN STRESS DISTRIBUTION FINITE ELEMENT ASTRA ANALYSIS

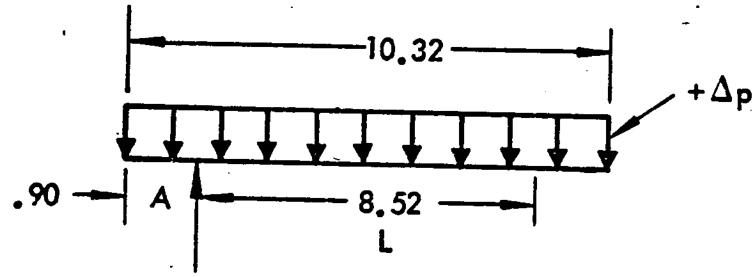
The following pages contain stress analyses of the panel details. The ASTRA finite element analysis showed a loading concentration at the outer corrugations due to the supports located at the panel corners. A loading concentration factor of 1.5 has been used for the corrugation analysis.

The panel was analyzed for maximum temperature Condition 2 using a limit airload pressure of 2.5 psi with the requirement that the resulting stresses should not exceed the allowable 1% creep stress. It was also checked to preclude exceeding material strength or buckling at an ultimate factor of safety equal to 1.5.

Edge Member Analysis

Loading Condition 2.

$\Delta p = + 2.5$ Psi Limit



$$M_{\mathbb{C}} = \frac{W}{8}(L^2 - 4A^2) = \frac{17.5}{8}(8.52^2 - 4(.90)^2) = 151.8 \text{ In-Lbs Limit}$$

Max. Temperature Profile (Reference Thermal Analysis)

$T\ (\text{Panel})_{max} = 1000°F$

T (Z Top Flange) $= 700°F$

T (Z Bottom Flange) $= 600°F$

Edge Member Section

Assume Upper Surface Stress Level = -10,000 Psi

Upper Flange @ 700°F $E_c = 11.55 \times 10^6$

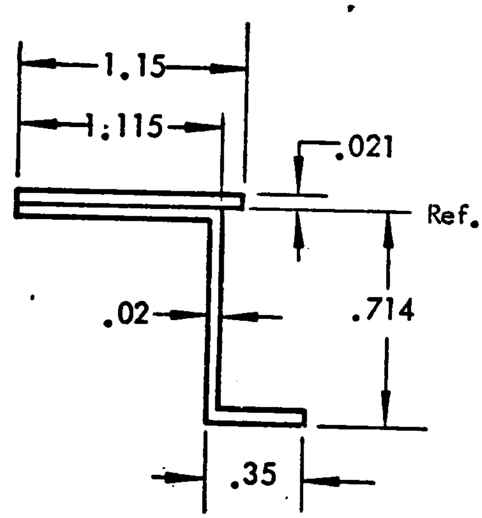
Effective Skin $= 1.7\ T\ \sqrt{E/F_c}$

Effective Skin $= 1.7(.02)\ \sqrt{\dfrac{11.55 \times 10^6}{10000}}$

$= 1.15$ In.

$\overline{Y} = -.147$ In.

$I_{N.A.} = .00445 \text{ In}^4$



Upper Flange Stress

$$F = \frac{Mc}{I} = \frac{151.8\,(-.147)}{.00445} = -5020 \text{ Psi Limit (Compression)}$$

Obviously not critical for creep, check buckling.

Upper flange is supported at each corrugation at a spacing "S" = 1.36"

$$K = .456 + (B/S)^2 = .456 + \left(\frac{1.095}{1.36}\right)^2 = 1.106$$

$$F_{cr} = \frac{K\,\pi^2 E}{12(1-\mu^2)}\left(\frac{T}{B}\right)^2 = \frac{1.106\ \pi^2\ 11.55 \times 10^6}{12(1-(.3)^2}\ \frac{.041}{1.095}^2 = 16,200 \text{ Psi}$$

$$M.S._{\text{Upper Flange}} = \frac{16,200}{1.5(5020)} - 1. = +1.15$$

Loading Condition 1

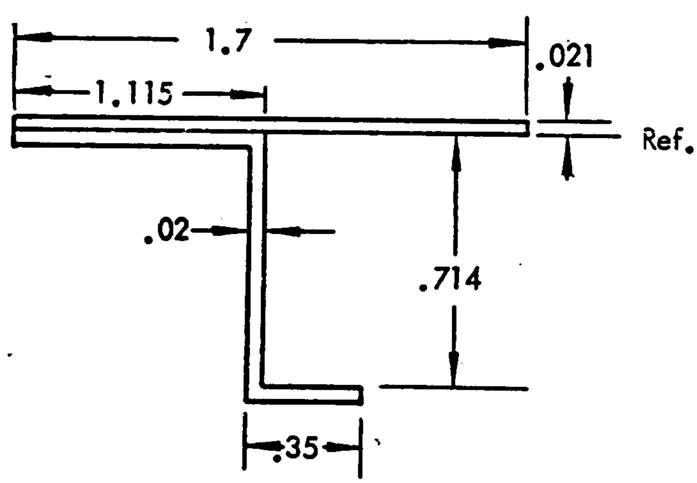
Δp = -3.64 Psi Ult.

Edge Member Section

Upper Surface in Tension Use 1.7 In. Eff.

$\overline{Y}$ = -.124 In.

$I_{N.A.}$ = .0047 In.^{4}



Lower Flange Stress

$T_{L\,wr\ Flange} = 400^\circ F \quad E_c = 12.7 \times 10^6 \ Lbs/In^2$

$M = 3.64/2.5\ (151.8) = 221\ In.\ Lbs.$

$$f = \frac{M\,c}{I} = \frac{221\,(-.60)}{.0047} = -28,200\ Psi$$

$$F_{cr} = \frac{K_w\,\pi^2\,E}{12(1-\mu^2)}\left(\frac{t_w}{b_w}\right)^2 \qquad \text{Ref. 4}$$

$$\frac{t_w}{t_f} = \frac{.02}{.02} = 1. \qquad \frac{b_f}{b_w} = \frac{.33}{.714} = .46$$

$K_w = 3.3$

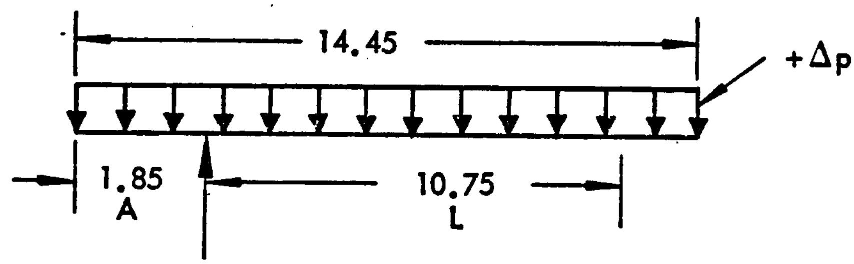
$$F_{cr} = \frac{3.3\,\pi^2\,12.7 \times 10^6}{12\,(1-(.3)^2}\left(\frac{.020}{.714}\right)^2 = 29,600\ Psi$$

$$M.S._{Lwr\ Flange} = \frac{29,600}{28,200} - 1. = +.05$$

Corrugation Analysis

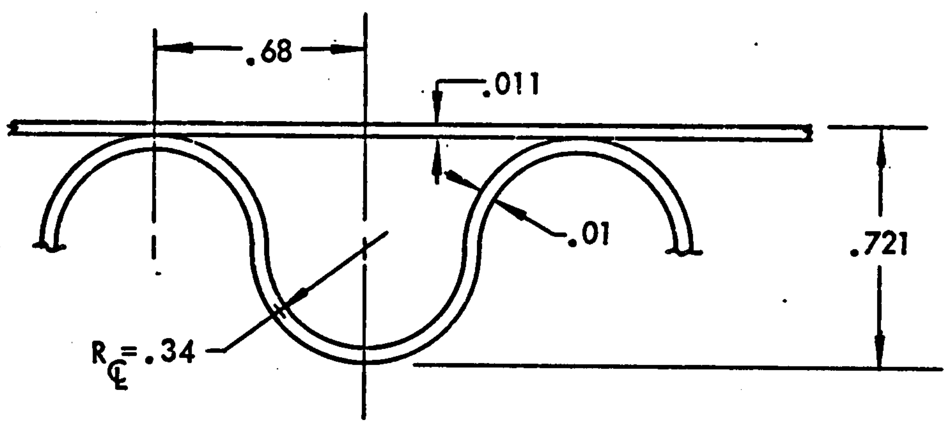
Loading Condition 2

Δp = +2.5 Psi Limit



$$M_{\mathbb{C}} = \frac{W}{8}(L^2 - 4A^2) = \frac{2.5}{8}(10.75^2 - 4(1.85)^2) = 31.8 \text{ In. Lbs Limit}$$

Panel Section



Assume Upper Surface Stress Level = -10,000 psi @ 800°F Max.

$$\text{Effective Skin} = 1.7\ T\sqrt{E/F_c} = 1.7(.011)\sqrt{\frac{11.20 \times 10^6}{10000}} = .63$$

$\overline{Y}$ = -.27 In.

$I_{N.A.}$ = .00140 In^4/In

Upper Surface Stress

* Use stress concentration factor = 1.5 along side of panel

$$f = \frac{Mc}{I} = \frac{31.8(-.27)\,1.5^*}{.00140} = -9,220 \text{ psi (Compression)}$$

Use 1% Creep Allowable @ 1000°F = 20,000 Psi

$$M.S. = \frac{20,000}{9220} - 1. = 1.17 \text{ (Creep)}$$

Lower Corrugation

* Use stress concentration factor = 1.5 along side of panel

$$f = \frac{Mc}{I} = \frac{31.8\,(.451)\,1.5^*}{.00140} = 15,400 \text{ psi (Tension)}$$

Conservatively use 1% creep allowable @ 1000°F = 20,000 psi

$$M.S. = \frac{20,000}{15,400} - 1 = +.30 \text{ (Creep)}$$

Loading Condition 1

$p = 3.64$ Psi Ult.

$$M = 31.8 \times \frac{3.64}{2.5} = 46.3 \text{ In-Lb. Ult.}$$

Panel Section

Use upper skin fully eff. in tension

$$\overline{Y} = -.209_{IN} \quad I_{N.A.} = .00175 \text{ In}^4/\text{In}$$

Lower Surface Stress

* Use Loading concentration factor = 1.5 along side of panel

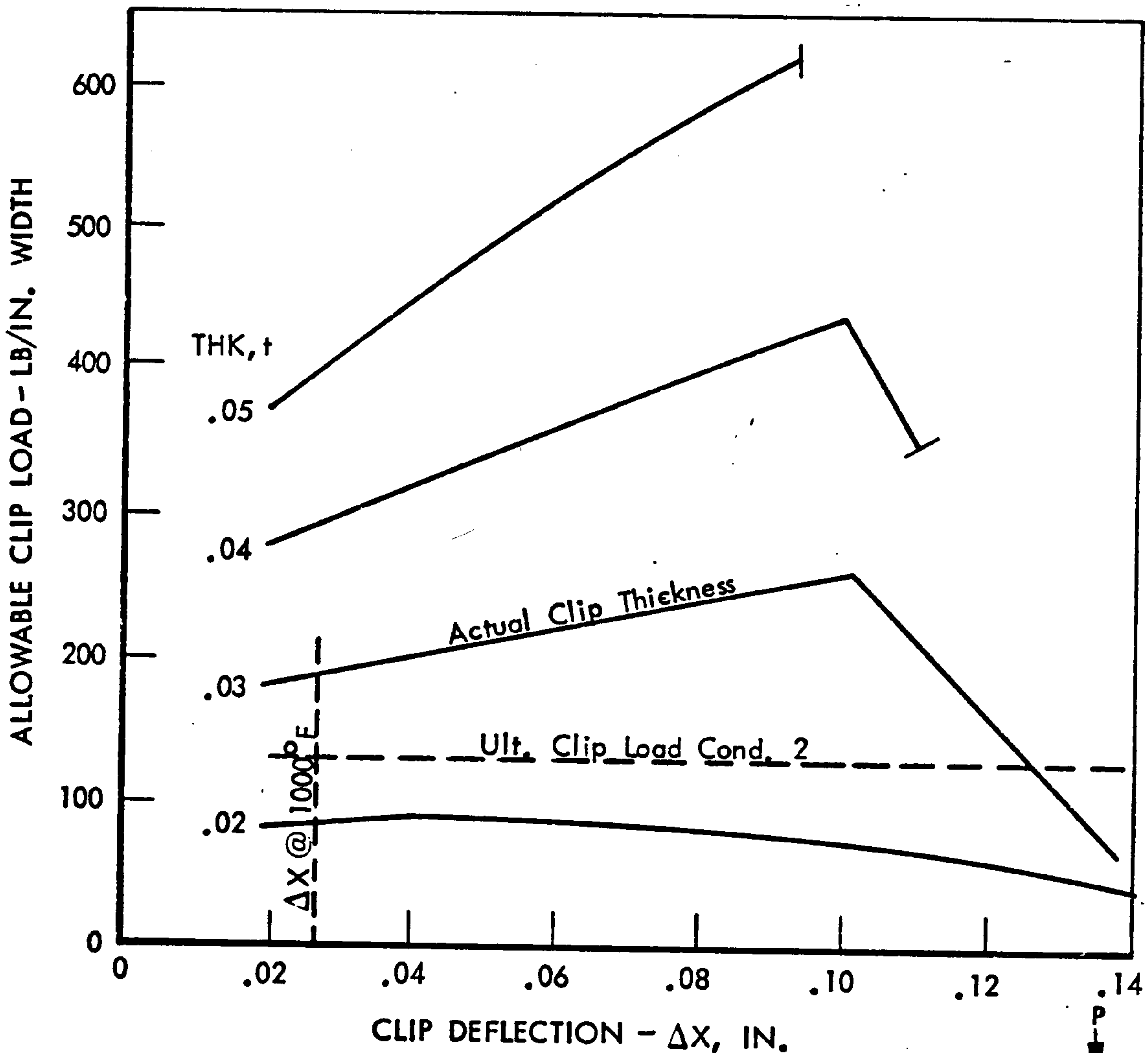
$$f = \frac{Mc}{I} = \frac{46.3\,(-.512)\;1.5^*}{.00175} = -20,200 \text{ Lbs/In}^2 \text{ (Compression)}$$

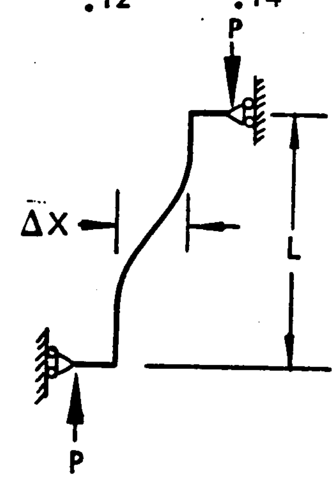
$$F_{cr} = .25\,E\;T/R = .25(11.2 \times 10^6)\;\frac{.01}{.34} = 82,000 \text{ Lbs/In}^2 \text{ (Crippling Stress)}$$

$$M.S. = \frac{82,000}{20,200} - 1 = +3.05$$

Figure 3-10 gives the allowable "Z" clip load as a function of displacement. Adequate clip strength is shown. The clip was also analyzed for an airload of -3.64 psi ultimate tension and had adequate strength.

Adequate margins of safety have been shown for all design conditions. The most critical location in the panel is the lower flange of the edge member. For the -3.64 psi ultimate pressure condition, the lower flange has a margin of safety of +.05.





F_{ty} Allowable = 100,000 psi

$$f = P/A + \frac{(\Sigma M)c}{(1 - P/P_{cr})} \quad \text{(Max. Stress)}$$

$$M.S. = F_{ty}/f - 1. \qquad P_{cr} = \frac{4\pi^2 EI}{L^2}$$

Figure 3-18: "Z" CLIP ALLOWABLE LOAD

3.2.3 Panel/Support System Modal Analysis

The TPS panel and support system natural modes and frequencies have been calculated for use in panel flutter and acoustic analyses. A schematic of the panel concept analyzed is shown in Figure 3-19. Thermal Protection System (TPS) panel drawing 180-10193 shown in Figure 7-1 defines panel details.

Structural Model

The panel is composed of three sections of corrugation stiffened skin with edge members connected by deep flexible omegas and supported by standoff clips as shown in Figure 3-19. This design allows the panel to act as three independent panels. Therefore, it was necessary to analyze only one section of the panel. Advantage was taken of the fact that a panel section has two lines of symmetry as shown in Figure 3-20, and only 1/4 of a panel section was modeled, which allowed a smaller mathematical model, and fewer degrees of freedom required to represent the total section. This was done since modal deflections for the complete panel section could be obtained by applying combinations of symmetric and anti-symmetric deflection constraints along lines of symmetry. For each of the deflection constraint conditions analyzed, only displacements representing vertical stiffness normal to the plane of the skin were used in the modal analysis. The panel finite element model is shown in Figure 3-21. The mathematical elements used in this model are described in the stress analysis portion of Section 3.2. The analysis was performed using nominal skin gages at room temperature conditions.

Modal Analysis

Three modal analyses were performed using lumped masses and vertical displacement

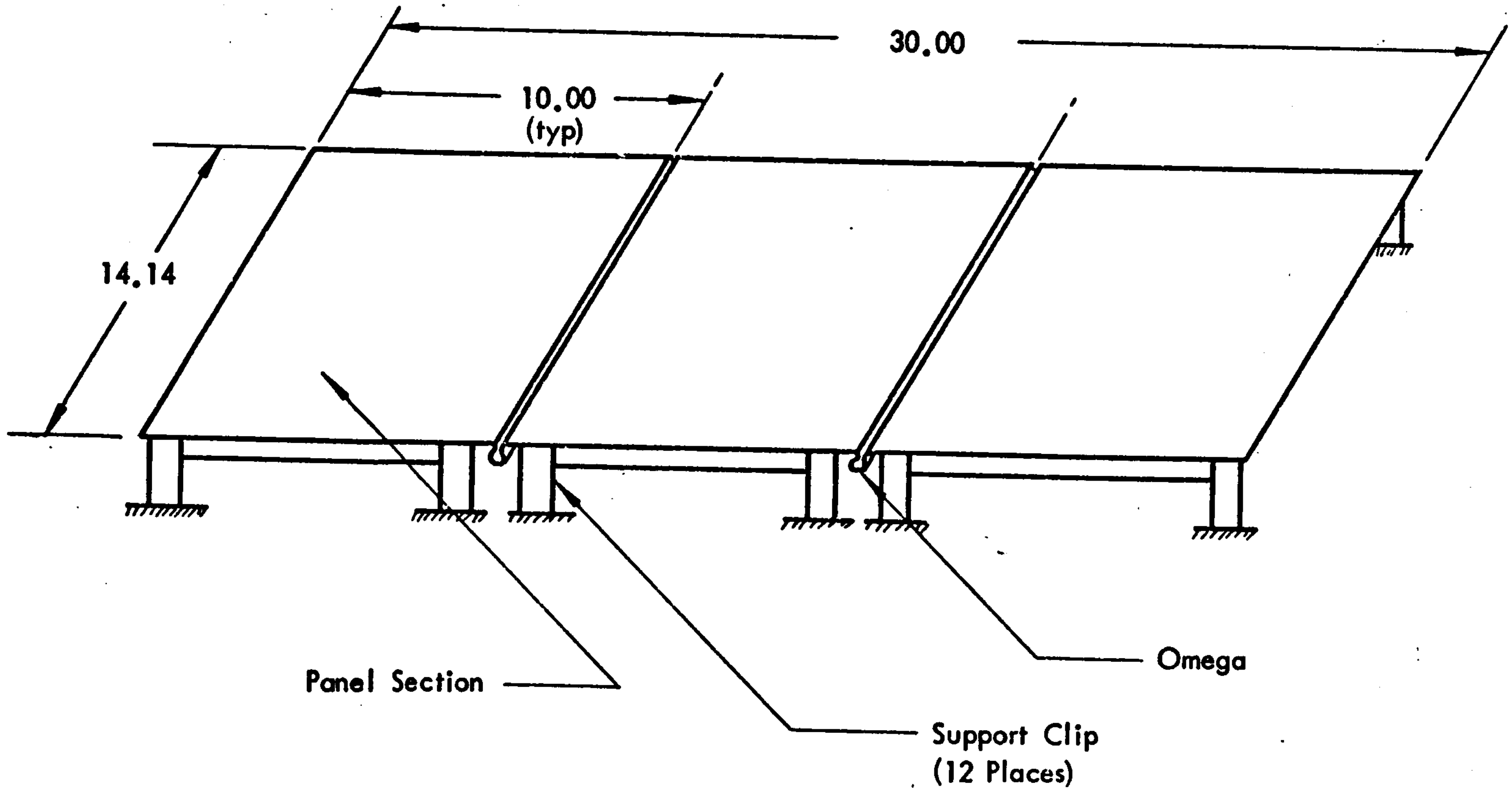


Figure 3-19: GENERAL PANEL ARRANGEMENT AND SUPPORT SYSTEM

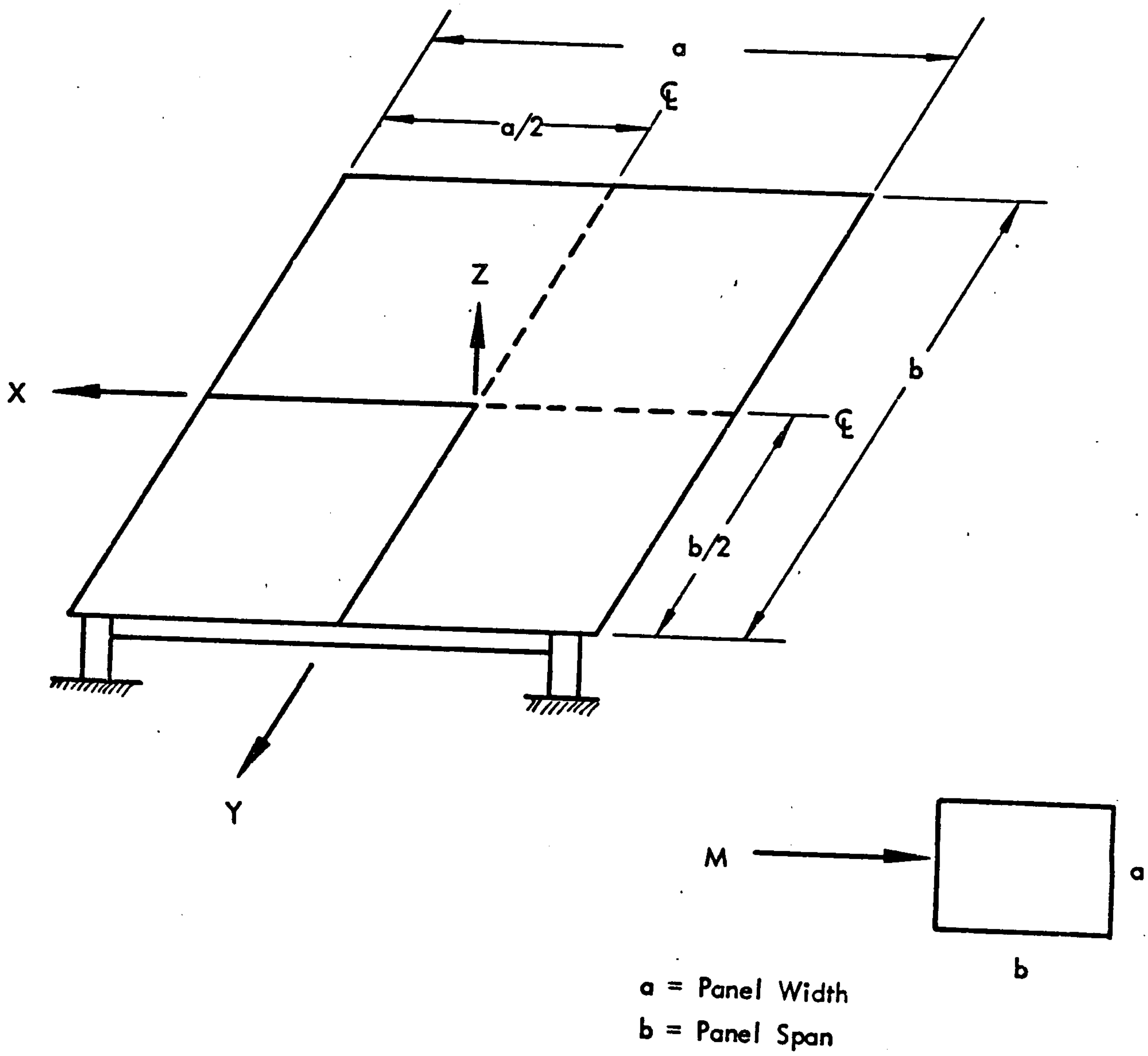


Figure 3-20: SECTION OF PANEL ANALYZED

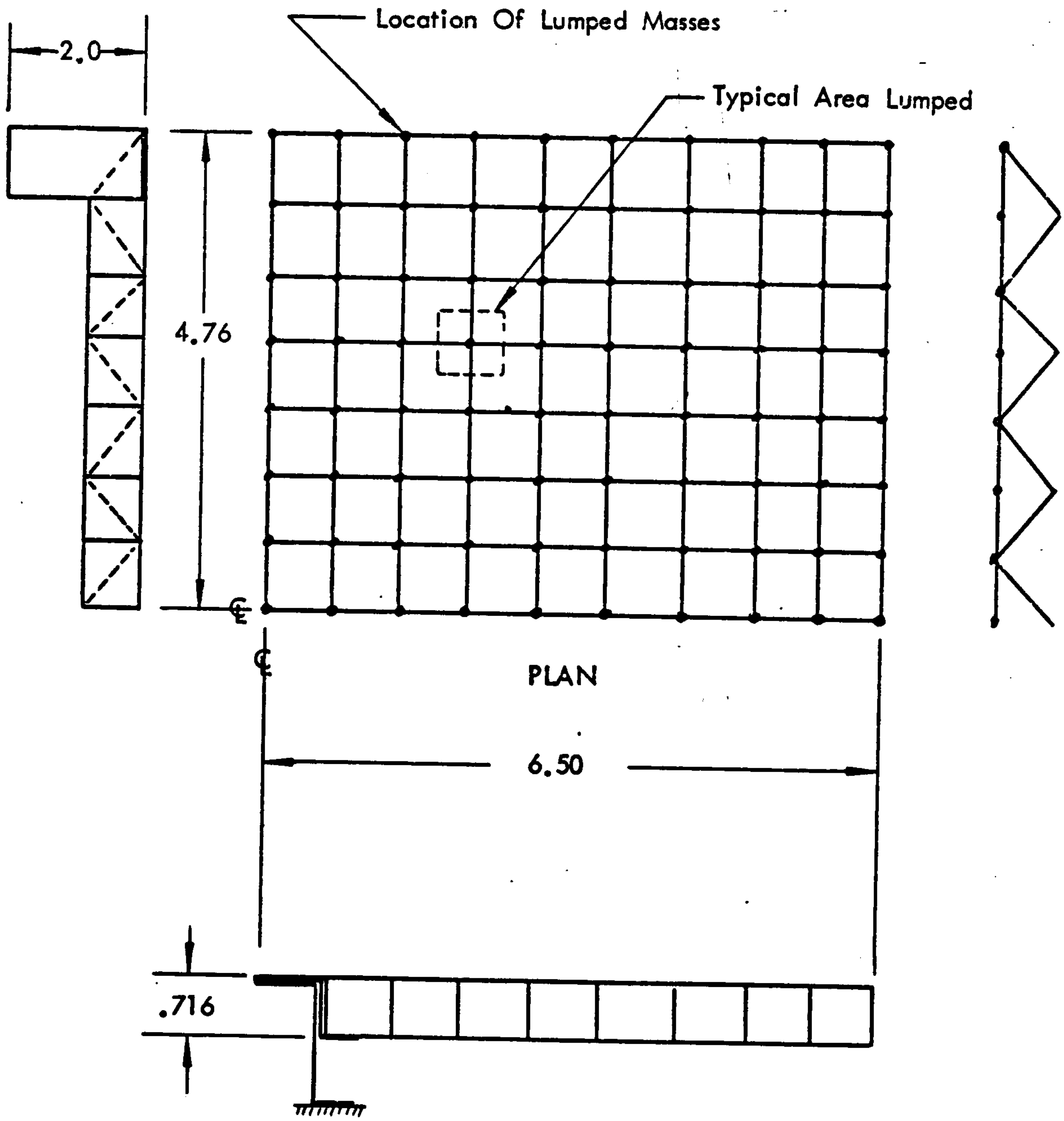


Figure 3-21: MATHEMATICAL MODEL

(Z – direction) stiffnesses for discrete points on the panel surface reflecting desired deflection constraints along lines of symmetry. The equations of motion in matrix form are:

$$\left[m\right] \left\{\ddot{Z}\right\} + \left[K\right] \left\{Z\right\} = 0$$

where m = mass matrix

K = stiffness matrix

Z = displacement in Z direction

$\ddot{Z}$ = acceleration in Z direction

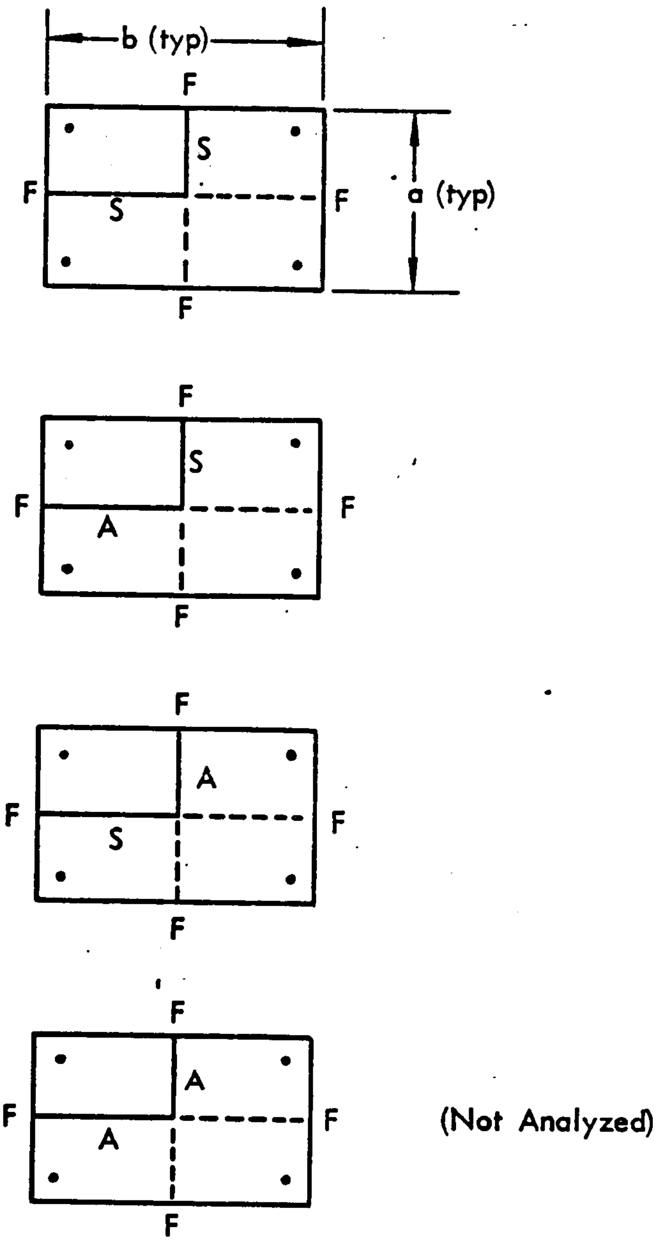
The deflection constraint conditions imposed along lines of symmetry to obtain modes of interest are shown in Figure 3-22. The condition of anti-symmetric deflection constraints along both lines of symmetry was not analyzed as this would produce modal frequencies of over 1000 Hz which are above the area of interest in the flutter or acoustic analyses. The equations of motion solved were of 80th order. Masses were lumped for vertical sections cuts through the panel, (the largest surface area lumped was 0.64 sq.in.).

The average panel weight is 1.005#/Ft^2 overall with the skin and corrugation making up 0.68#/Ft^2 of this.

The results of the modal analysis for six of the first 18 modes obtained are presented in Figure 3-23. The frequencies are high and quite well separated.

Modal Analysis Check

A check of analysis results was made using panel stiffness data of Section 3.3 and vibration formulas of Reference 5 . Taking a single corrugation and treating it as a simple beam with a uniform mass, the following first mode frequency is obtained.



• – Support Points

S – Symmetric Deflection Constraint

A – Anti-Symmetric Deflection Constraint

F – Free Edge

Figure 3-22: PANEL SECTIONS SHOWING DEFLECTION CONSTRAINTS AND EDGE CONDITIONS

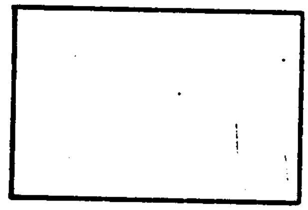
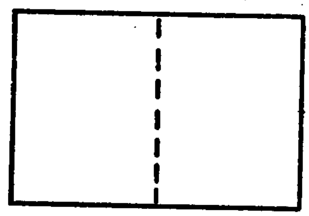
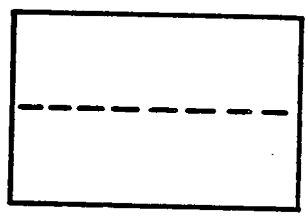
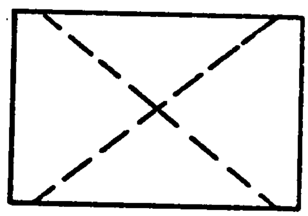
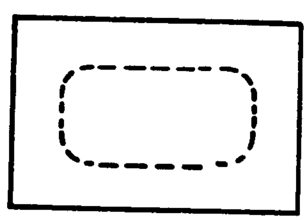
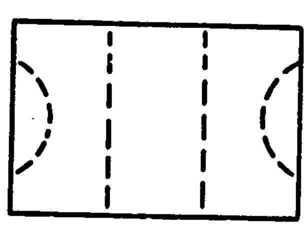
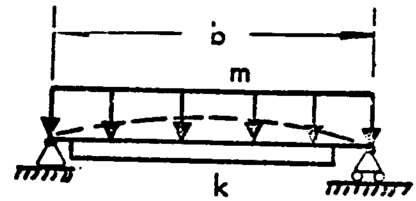
Mode Number	Frequency (HZ)	Panel Node Lines	Mode Frequency Differences
1	420		192
2	612.6		96
3	708.9		266
4	974.8		272
5	1246.2		424
6	1670.9		118

Figure 3-23: PANEL/SUPPORT SYSTEM MODAL DATA



$EI = 2.54 \times 10^4$ lb. - in^2

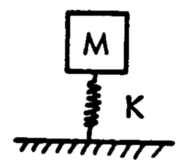
$b = 13.0$ in.

$k = 2\,EI/b = 314 \frac{\#}{in.}/in.^2$

$m = 2.42 \times 10^{-5} \quad \frac{lbs. - sec^2}{in.}/in^2$

$Freq = 1/2\pi\sqrt{k/m} = 574$ Hz

Placing 1/4 of a panel section mass on one support clip as a spring mass system provides the panel/support translational frequency.



$M = 5.5 \times 10^{-4} \quad \frac{lbs. - sec^2}{in.}$

$K = 5040$ #/in.

$Freq = 1/2\pi\sqrt{K/M} = 490$ Hz

These check well with the 420 Hz first mode frequency shown in Figure 3-23 which was obtained using a combination of panel bending and support deflection.

3.2.4 Panel Flutter Analysis

In the design of this panel one of the considerations was panel flutter. Using guidelines developed on the X-20 (Dyna-Soar) and other programs, the panel was designed for strength and then checked for flutter. Applying these guidelines resulted in a panel having high well separated frequencies.

On the X-20 Program Boeing developed analytical tools for use in predicting panel capability. One of these was a two-mode flutter solution. This solution was developed using assumed sine functions as modes, zero structural damping and piston theory aerodynamics. The equation as presented below is derived in reference 6 , is a measure of panel capability as a function of frequency separation.

$$\frac{q^2}{M^2-1} = \frac{-m^2 \left(\omega_{n+1}^{\;2} - \omega_n^{\;2}\right)^2}{\dfrac{1.94768 \times 10^{-3} \left(\omega_{n+1}^{\;2} + \omega_n^{\;2}\right)}{V^2} - \dfrac{256\ n^2}{a^2} \left(\dfrac{n^2+2n+1}{4n^2+4n+1}\right)}$$

where:

q = flutter dynamic pressure - PSI

M = flutter Mach number

V = flutter velocity - knots

a = panel chord in inches

m = panel mass $\dfrac{\# - sec^2/in^2}{in.}$

n = mode number considered

$(n+1)$ = next highest mode number

ω_n = frequency in radians/sec. of the nth mode

ω_{n+1} = frequency in radians/sec. of the nth +1 mode

To perform a check on this panel the second and third modes are used as these have the lowest frequency difference, and will yield the lowest dynamic pressure capability.

The values used in the evaluation are:

$$a = 10 \text{ inches}$$

$$m = 0.38 \times 10^{-5} \ \frac{\#\text{-sec}^2}{\text{in.}} \text{ per in}^2$$

$$\omega_2^{\,2} = 148 \times 10^5 \text{ rad}^2/\text{sec}^2$$

$$\omega_3^{\,2} = 198 \times 10^5 \text{ rad}^2/\text{sec}^2$$

thus substituting into the above equation gives

$$\frac{q^2}{M^2-1} = \frac{-364}{\dfrac{67.8 \times 10^4}{V^2} - 3.78}$$

The solution is iterative requiring that M and V be compatible in a solution. However a minimum value for q can be obtained by setting V to a large number, thus

$$q^2 = \frac{-364\ (M^2-1)}{-3.78}$$

$$\text{or} \quad q = 9.6 \sqrt{M^2-1} \text{ PSI} = 1340 \sqrt{M^2-1} \quad \text{PSF}$$

and since the minimum q is obtained at approximately $M = \sqrt{2}$, $q_{min} \cong 1340$ PSF. This gives a factor of 2.23 times the local dynamic pressure expected of 600 psf compared with the margin of 1.50 required by reference 1 . No pressure differential is used in this analysis. Consequently, the calculated margin is conservative. A further check of panel capability was made using X-20 panel flutter test data from reference 7 as shown in Figure 3-24. . The panels tested were Rene' 41 panels which had a pitch of 1.5 inches and approximately the same depth as the proposed shuttle panel. The width, however, is much greater, 42.8 inches compared to 10 inches, and without correcting for this, the results are conservative. A value of 2300 PSF for dynamic pressure

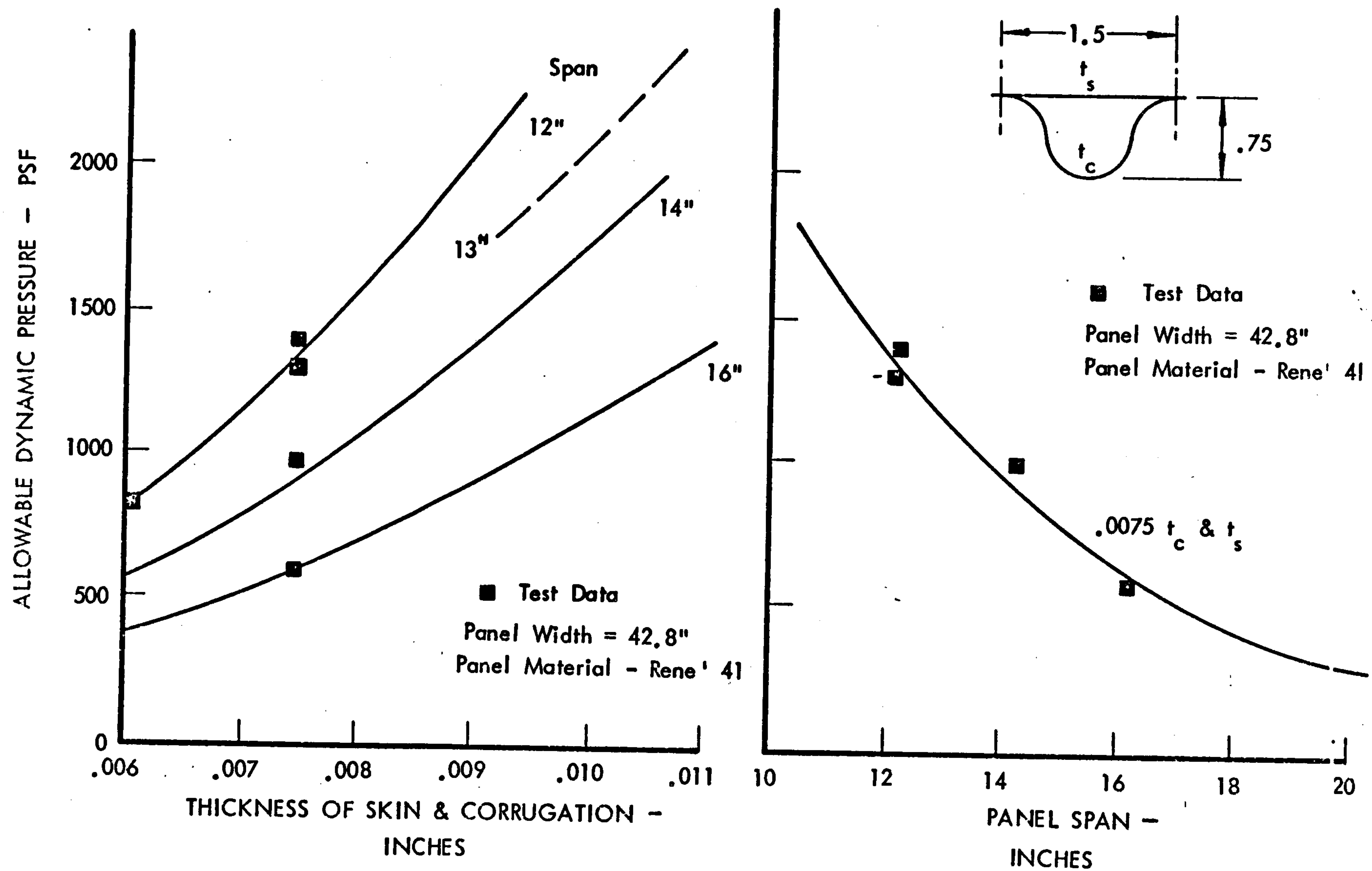


Figure 3-24: SPAN AND THICKNESS EFFECTS
Reference 7

can be extrapolated for a panel of 13 inch span and a skin and corrugation gage of 0.011 inches. This, however, must be corrected by the ratio of material modulus of elasticity which is $E_{Ti}/E_{Rene'} = 0.5$. Thus the allowable dynamic pressure = 2300 (.50) = 1150 PSF which is considered very conservative.

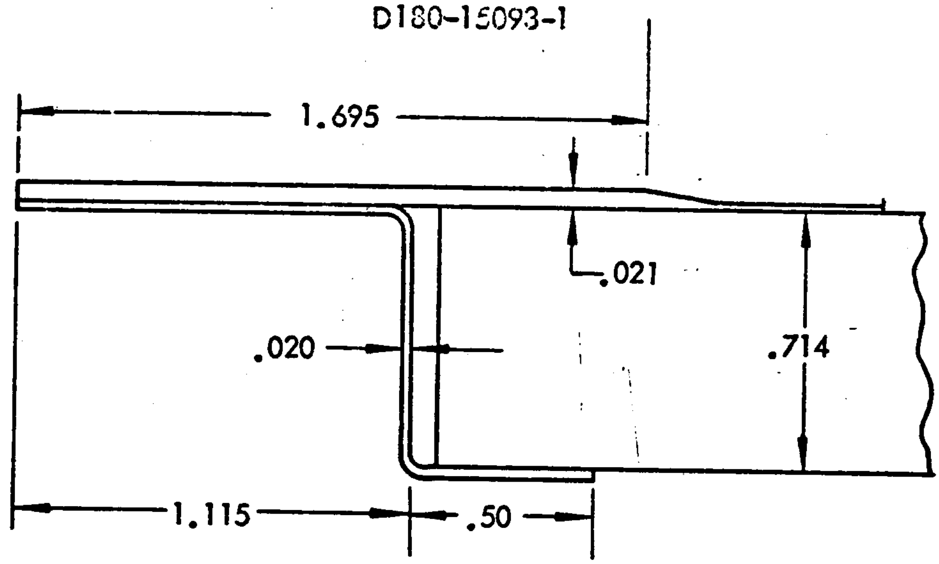
Next, the data from a recent NASA report, reference 8 , on the effects of panel support stiffness and bending stiffnesses was used to check the proposed panel. The panel parameters required to check the panel as shown in Figure 3-26 are:

a	= 10.0 in.	Width
b	= 13.0 in.	Span
D_1	= 1.7 #-in^2	Cross corrugation bending stiffness
D_2	= 25400 #-in^2	Corrugation bending stiffness
k_D	= 5000 #/in	Support deflection stiffness
k'_D	= 1540 #/in	Average edge member deflection stiffness

Calculating the panel support stiffness K_D and the flutter parameter λ_{cr} according to the relationships below

$$K_D = \frac{k'_D \; b^3}{\pi^3 D_2} \quad \text{and} \quad \lambda_{cr} = \frac{2qb^3}{D_2 \sqrt{M^2-1}}$$

and using the average edge member stiffness k'_D to compute K_D a value of 4.3 is obtained. This yields a value of $\lambda_{cr} = 130$ as shown in Figure 3-27 . Solving for a dynamic pressure at $M = \sqrt{2}$ check yields a value of 1090 PSF. This value is conservative since the deflection stiffness was averaged for the edge member between the



Reférence Figure 7-1

Figure 3-25: DETAIL CORRUGATION END SUPPORT

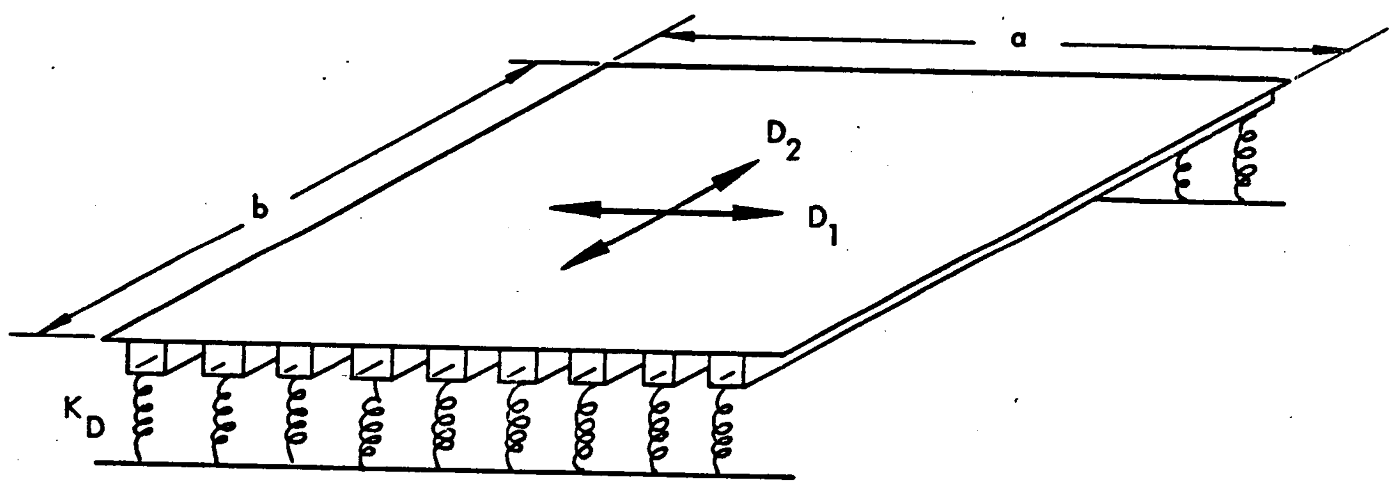


Figure 3-26: PANEL PARAMETERS

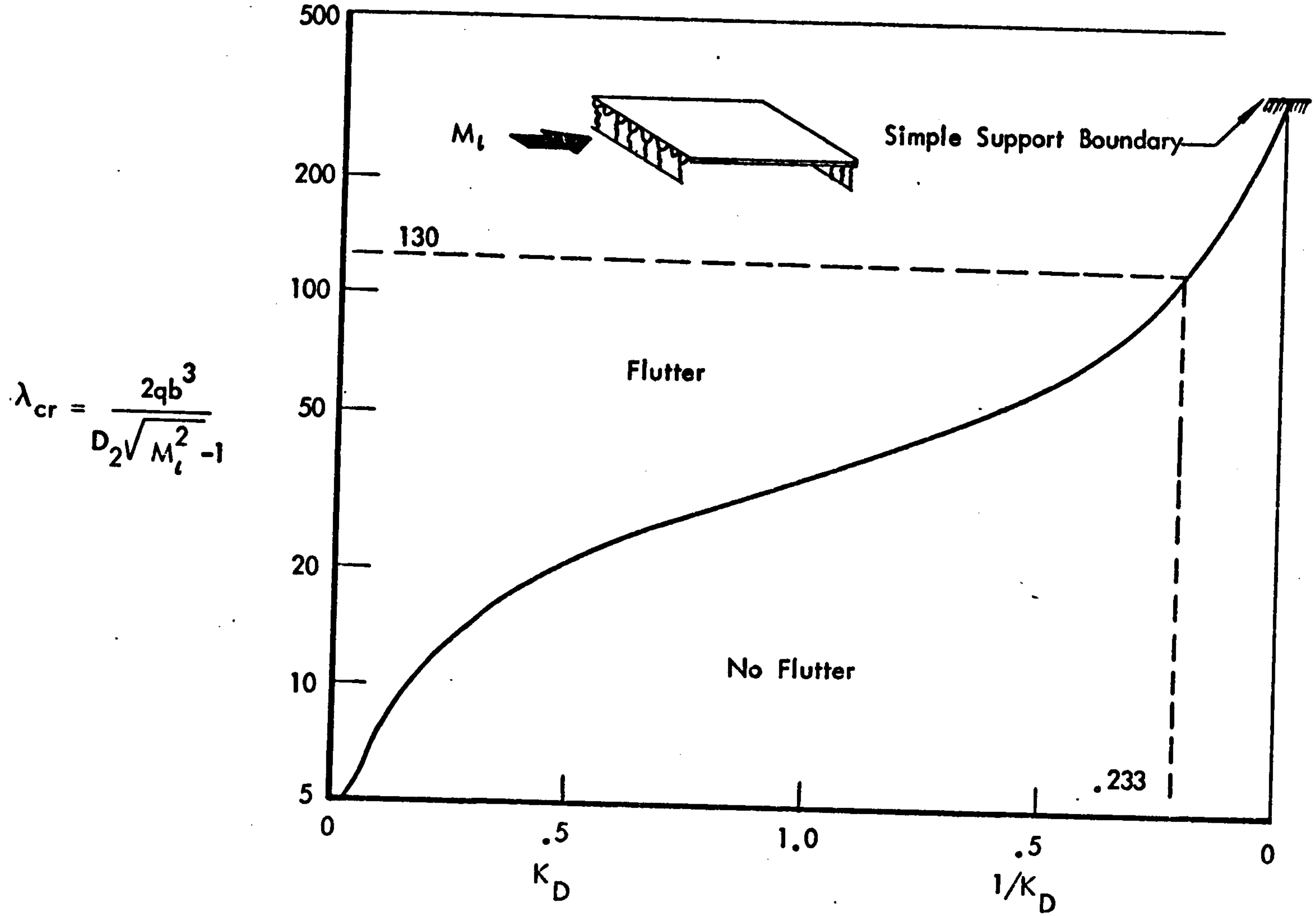


Figure 3-27: MINIMUM FLUTTER BOUNDARY FOR HIGHLY ORTHOTROPIC PANELS WITH FLOW IN STRONG DIRECTION

REFERENCE 8

supports. The author of reference 8 also suggests the solution is often conservative. The reference report presented flutter margin increases by a factor of six for corrugation end support similar to that of this panel as shown in Figure 3-25.

An inter corrugation flutter check of the unsupported skin was made using the Air Force data of reference 9 . Shown in Figure 3-28 is a flutter boundary as a function of panel skin thickness, modulus of elasticity, and length to width ratio. The parameters for this panel are:

Pitch (w) = 1.36 in.	$E = 15.1 \times 10^6$ PSI
Length = Span (ℓ) = 13 in.	$t_B = 0.011$ in.
	$f(m) = \sqrt{M^2 - 1}$

The following computation was performed. For a length/width ratio of (ℓ/w) = 9.55 the value of $\left[f(m)E/q\right]^{1/3} \times t_B/\ell$ from the curve of Figure 3-28 must be greater than 0.078. Solving for the allowable dynamic pressure at $M = \sqrt{2}$ a value of 1590 PSF is obtained.

The results of the panel flutter checks are summarized in Figure 3-29. It is noted that the panel is flutter free for the expected design environment yielding a minimum factor on dynamic pressure of 1.55.

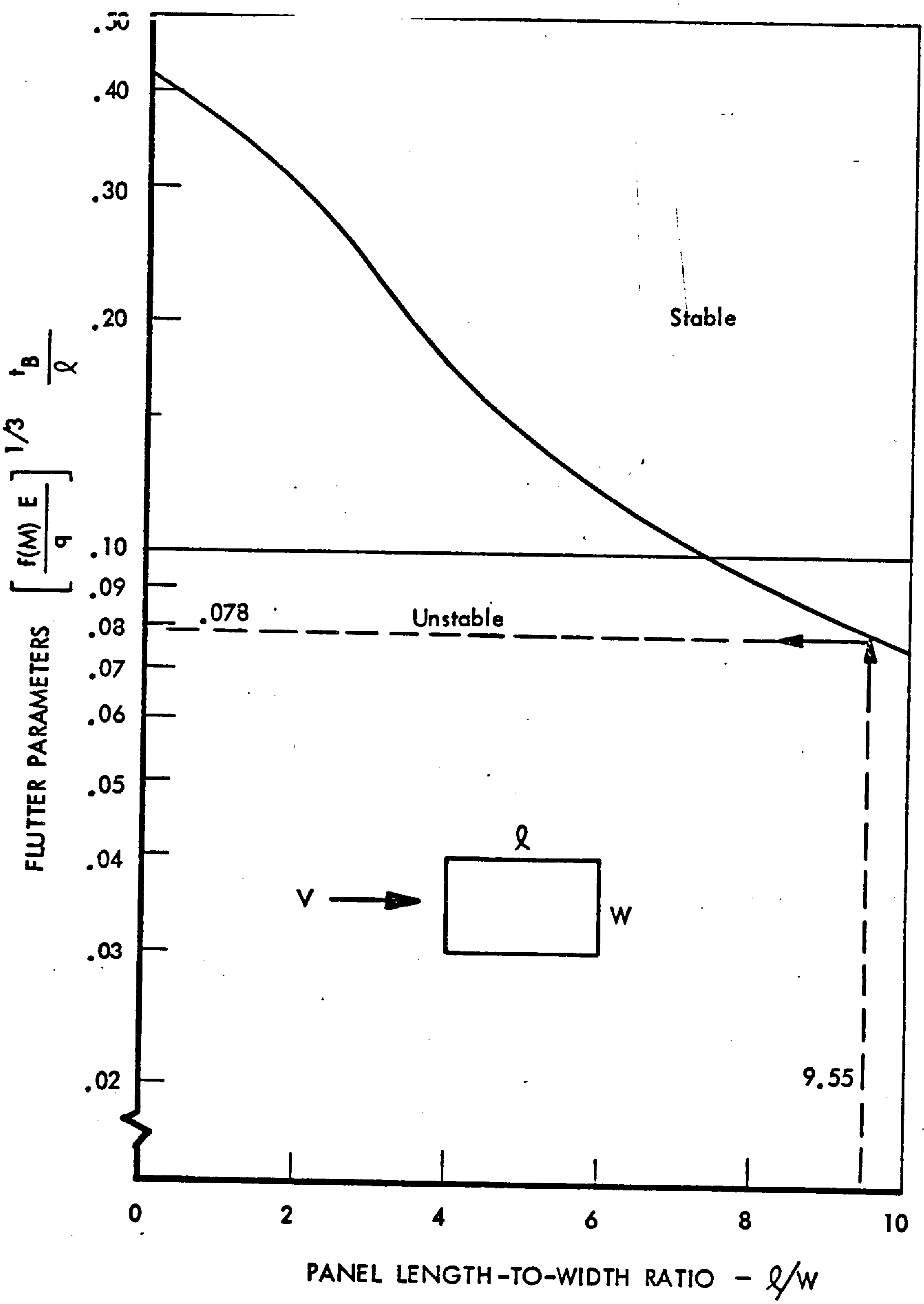


Figure 3-28: UNSTIFFENED FLAT PANEL DESIGN PARAMETERS
REFERENCE 9

$M = \sqrt{2}$

Item	Reference	Flutter Dynamic Pressure		Ratio of Flutter q_F To Design q – $q_F/600$ [1]	
		Ascent Rm. Temp.	Re-Entry 800°F	Ascent Rm. Temp.	Re-Entry 800°F
Overall Panel Flutter	Ref. 6, Boeing Dyna-Soar	1340	1140	2.24	1.90
	Ref. 7, Boeing Dyna-Soar	1150	975	1.92	1.63
	Ref. 8, NASA	1090	925	1.81	1.55
Inter Corrugation Skin Flutter	Ref. 9, Air Force Doc.	1590	1350	2.66	2.26

[1] Requirement per Reference 1 is 1.50

Figure 3-29: SUMMARY OF TITANIUM PANEL FLUTTER RESULTS

3.2.5 Acoustic Analysis

Acoustic Environmental Characteristics

The prediction of acoustic environment and panel response are important features of preliminary design evaluation. The preliminary procedures used for prediction include noise scaling based on measured noise data from model and full scale rocket tests. These noise field predictions considered:

1) Identification of significant flow parameters.
2) Configuration dependent features.
3) Directional characteristics.
4) Effects of nozzle clustering.

Using the above methods a power spectrum associated with a given geometrical location was defined. Overall noise level variation along the centerline of the vehicles is shown in Figure 3-30. A typical acoustic environment and resulting power spectrum are shown in Figures 3-31 and 3-32. The panel acoustic pressure loads were then evaluated by using:

1) Fundamental panel frequencies.
2) Detail stress analysis for a unit load condition.
3) Cumulative load expectancy and design life requirements.
4) Panel structural fatigue characteristics.

The panel support structure (standoff clips) was also analyzed.

The fundamental frequency of the panel is 400 cps as calculated in the modal analysis previously. The mean stress (RMS) was calculated using the following equation:

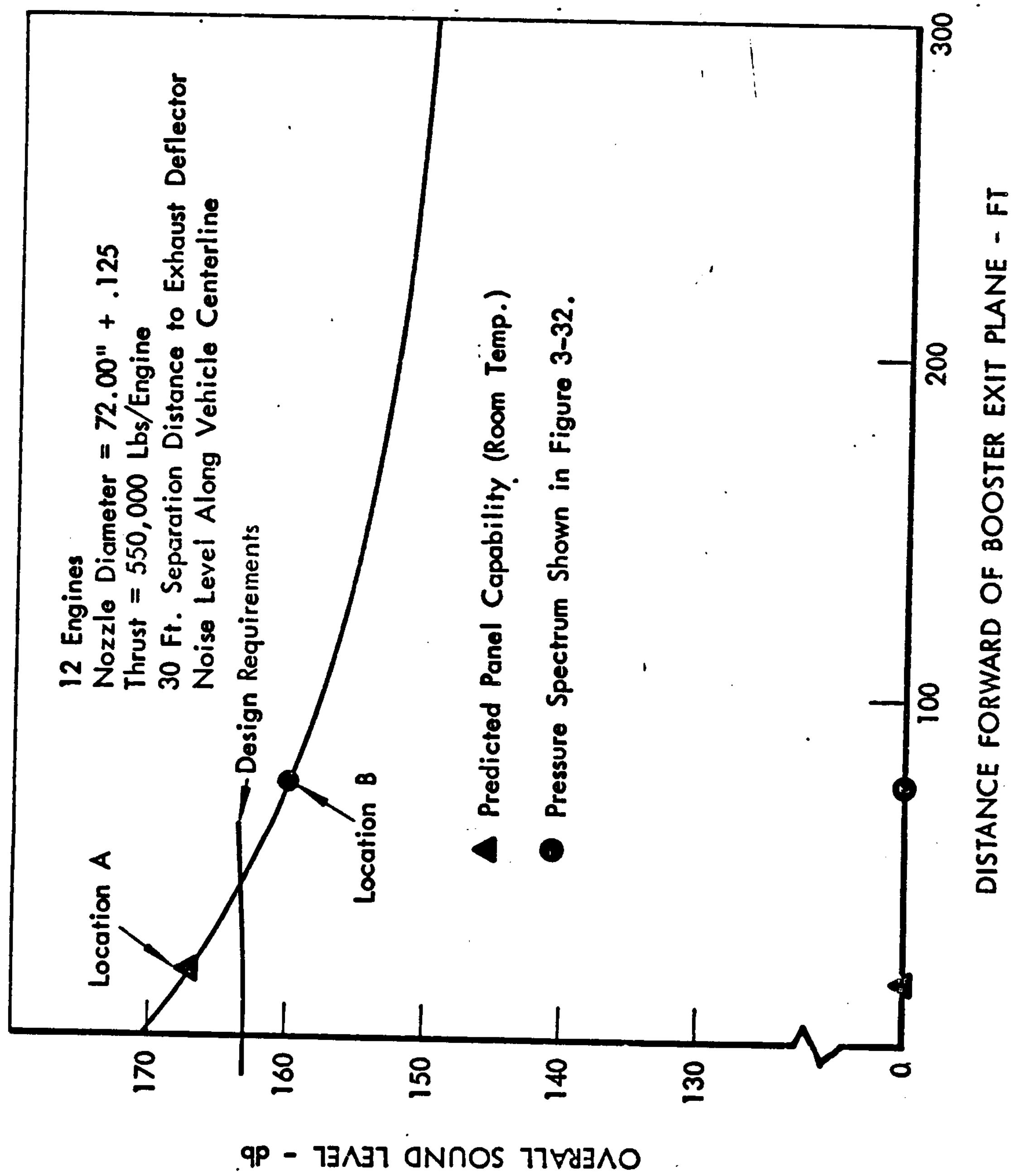
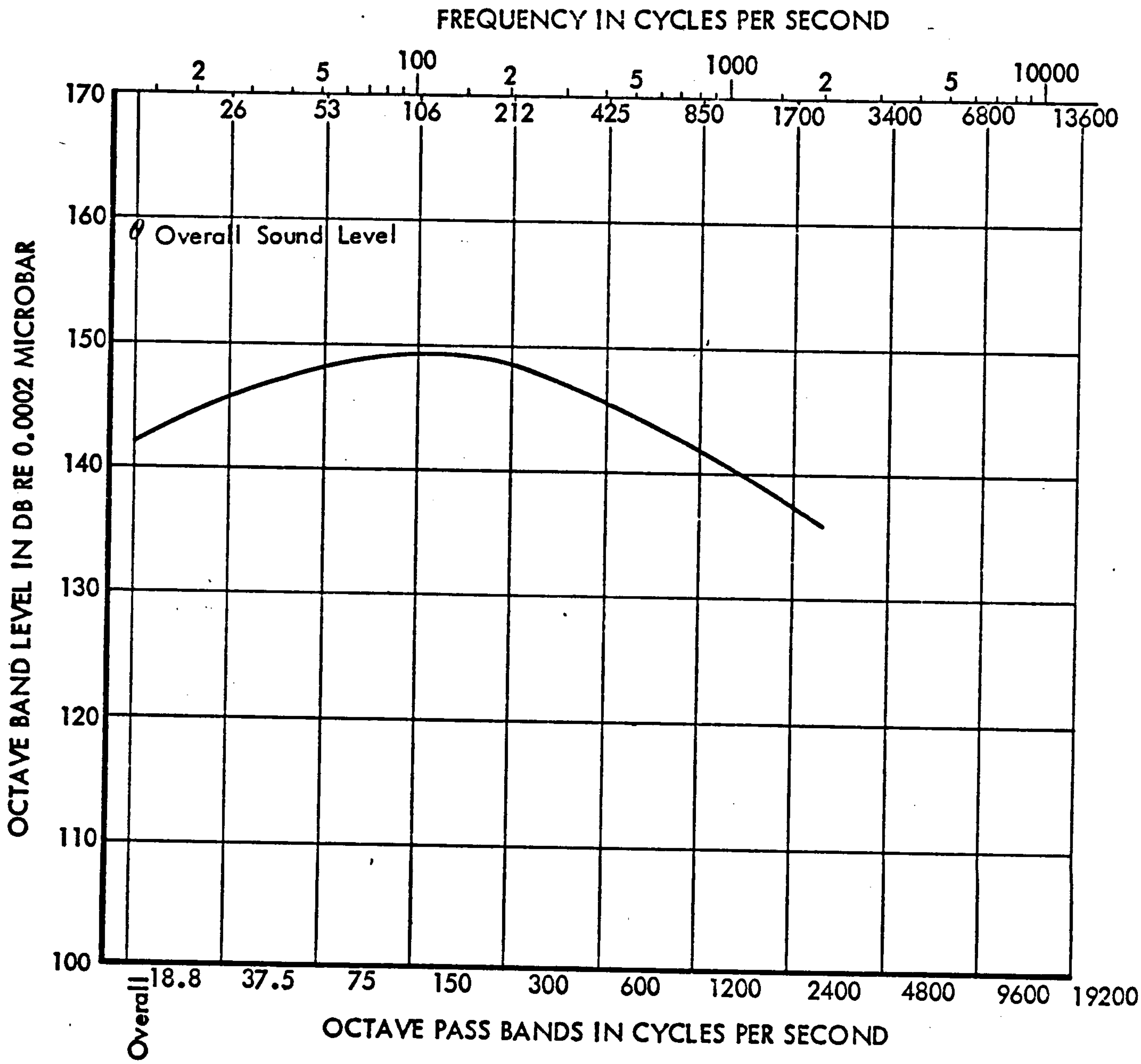


Figure 3-30: VEHICLE OVERALL NOISE LEVEL



Noise Level 75Ft. Forward of Nozzle Exit Plane
(Max Acoustic Environment for Orbiter)
30 Ft. Separation Distance to Exhaust Deflector

Figure 3-31: EXTERNAL ACOUSTIC ENVIRONMENT

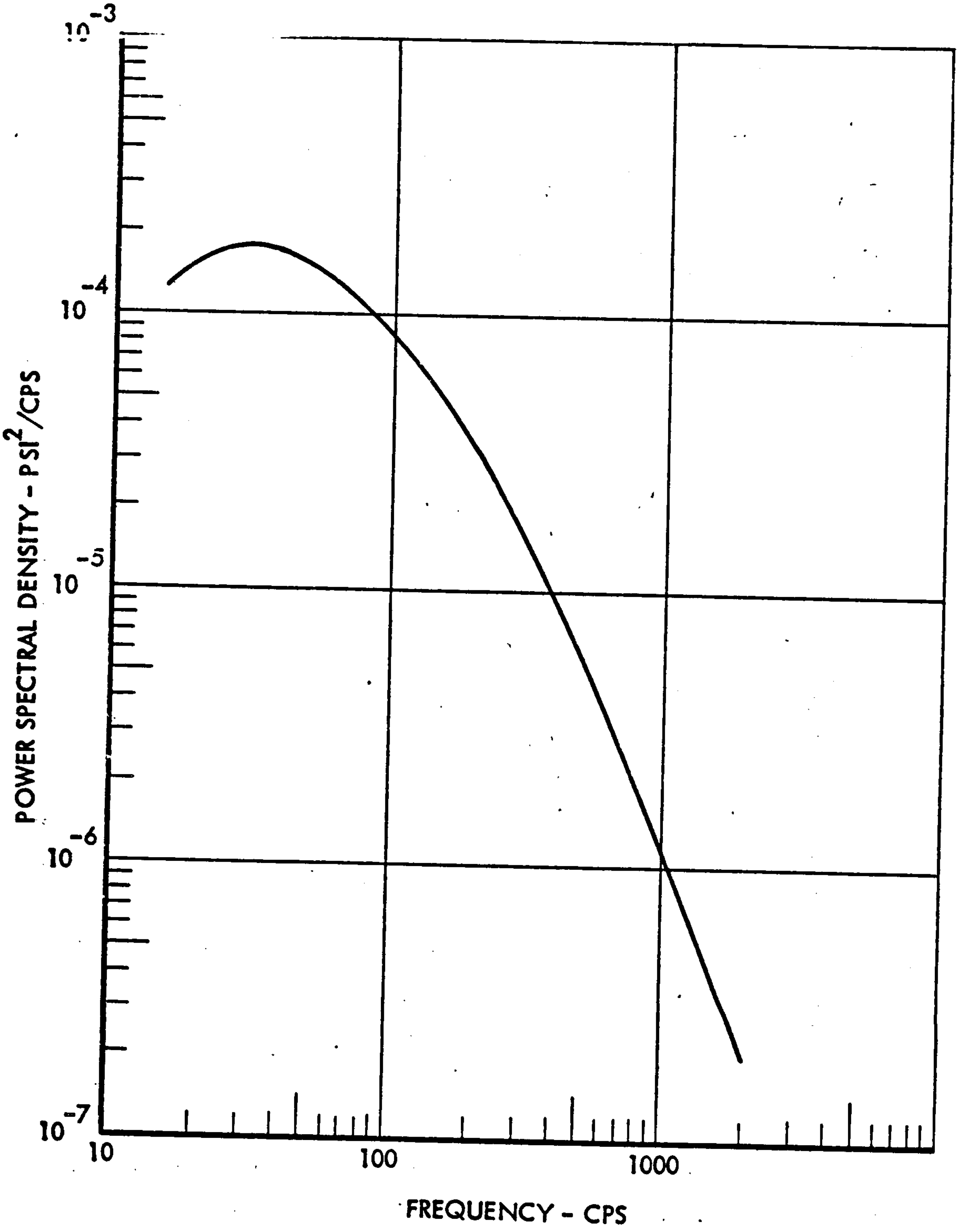


Figure 3-32: POWER SPECTRUM 75 FT. FORWARD OF BOOSTER NOZZLE EXIT PLANE

$$\overline{S_o}^2 = \frac{\pi}{4\delta} \quad f_o \, S_1^{\,2} \, (W(f))$$

where S_1 = stress due to 1 psi static pressure

f_o = fundamental frequency

$W(f)$ = power spectral density (Psi^2/Cps)

δ = critical damping ratio $C/C_c \cong .02$

The peak stress is $\sqrt{2}$ x mean stress.

The number of stress reversals due to launch environment alone was calculated as follows:

$$N = (f_m)\,(t)\,(FLF)$$

FLF = Fatigue Life Factor

N = number of stress reversals

f_m = primary response mode frequency = 400 cps

t = total time

$$\therefore \quad N = (400 \text{ cps})\ (100 \text{ flights})\ (40 \text{ sec/flight})\ (4) = 6.4 \times 10^6$$

The maximum allowable stress at this number of stress reversals is about 38,000 PSI for notched room temperature annealed sheet as shown in Figure 3-33.

The stress level in the basic panel due to launch acoustic excitation at Location B in Figure 3-30 is less than 1000 psi. This indicates infinite life capability. The panel capability for 100 missions is estimated to be 166 db overall which is shown as Location A in Figure 3-30.

The equivalent static load in 3 principle axes on the support structure was found to be 2 g's and is not critical.

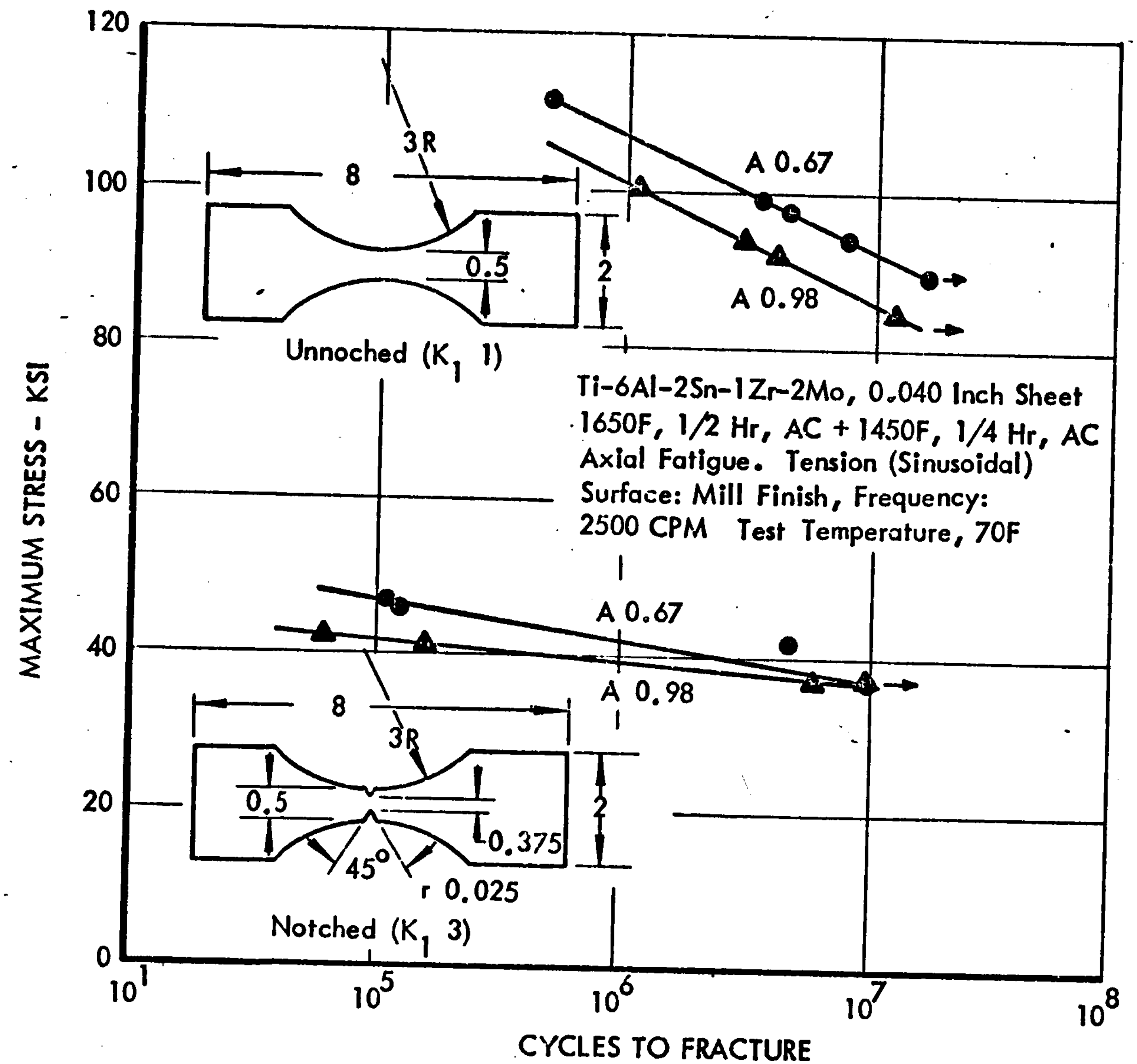


Figure 3-33: AXIAL LOAD SMOOTH AND NOTCH FATIGUE PROPERTIES AT 70°F FOR DUPLEX ANNEALED SHEET

3.2.6 Weight Analysis

The complete weight breakdown statements for the 180-10193-9 (2 bay) panel and the 180-10193-12 (3 bay) panel are shown in Figures 3-34 and 3-35 respectively. Based on the weight shown in Figure 3-35, the calculated nominal unit weight for the 3 bay panel is 1.20 lbs/ft^2. The actual measured average unit weight of the delivered 3 bay panels is 1.21 lbs/ft^2.

180-10193-9 RESISTANCE WELD PANEL ASSEMBLY

WEIGHT BREAKDOWN		
PART NO.	QTY.	WEIGHT (Lb)
180-10193-10	1	1.559
180-10193-8	(2)	(.597)
180-10193-11	(1)	(.962)
180-10194-4	8	.302
180-10194-10	12	.113
180-10194-11	4	.014
180-10194-12	4	.014
180-10194-19	2	.144
180-10194-20	2	.144
180-10104-26	2	.100
180-10194-28	2	.057
180-10194-31	1	.002
180-10194-32	1	.002
NAS 1218-06C-2	20	.047
Contingency (2%)	-	.050
TOTAL WEIGHT		2.548

Figure 3-34: TPS PANEL 180-10193-9 WEIGHT STATEMENT

180-10193-12 RESISTANCE WELD PANEL ASSEMBLY

WEIGHT BREAKDOWN		
PART NO.	QTY.	WEIGHT (Lb.)
180-10193-6	1	2.356
180-10193-7	(1)	(1.460)
180-10193-8	(3)	(.896)
180-10194-4	12	.452
180-10194-5	2	.106
180-10194-6	1	.051
180-10194-7	2	.061
180-10194-8	1	.029
180-10194-10	18	.169
180-10194-11	6	.021
180-10194-12	6	.021
180-10194-19	2	.144
180-10194-20	2	.144
180-10194-31	4	.010
180-10194-32	4	.010
180-10194-33	2	.144
NAS 1218-06C-2	30	.070
Contingency (2%)	-	.076
TOTAL WEIGHT		3.864

Figure 3-35: TPS PANEL 180-10193-12 WEIGHT STATEMENT

3.3 Stiffness Data

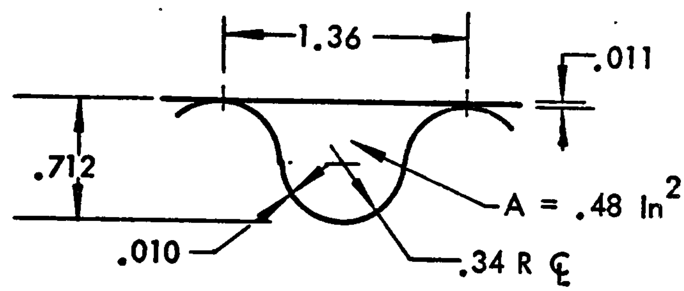
Presented here are computed panel stiffnesses, and the panel standoff support stiffnesses based on room temperature material properties.

3.3.1 Panel Stiffness

Panel bending stiffnesses are computed in the spanwise and chordwise directions using the nominal dimension and skin gages shown in Figure 7-1. Presented in Figure 3-36 is panel bending stiffness versus span. Cross corrugation bending stiffnesses are presented in Figures 3-37 and 3-38 for the center panel region and edge member, respectively.

The twisting stiffness of a single corrugation per unit width is computed below:

$$K_T = \frac{GJ}{P}$$



$$J = \frac{4A^2}{\int \frac{ds}{dt}}$$

$$= \frac{4(.48)^2}{\frac{1.36}{.011} + \frac{2.14}{.010}}$$

$$= 2.72 \times 10^{-3} \ \text{In}^4$$

$$G = 5.68 \times 10^6 \ \#/\text{In}^2$$

$$P = 1.36 \ \text{In}$$

$$K_T = \frac{(5.68 \times 10^6)(2.72 \times 10^{-3})}{1.36} = 11,400 \ \# \ \text{In}^2/\text{In}$$

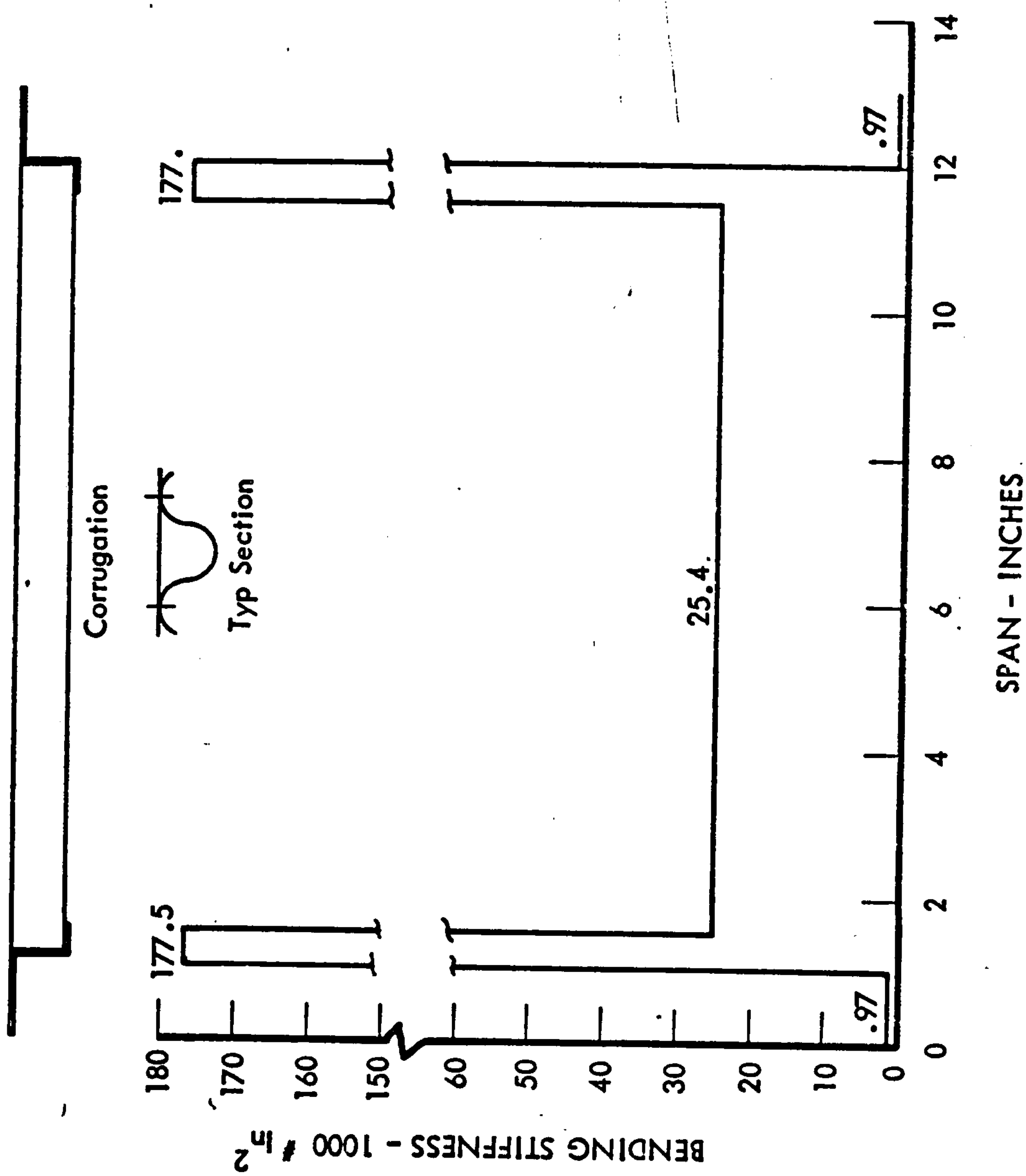


Figure 3-36: SPANWISE PANEL BENDING STIFFNESS

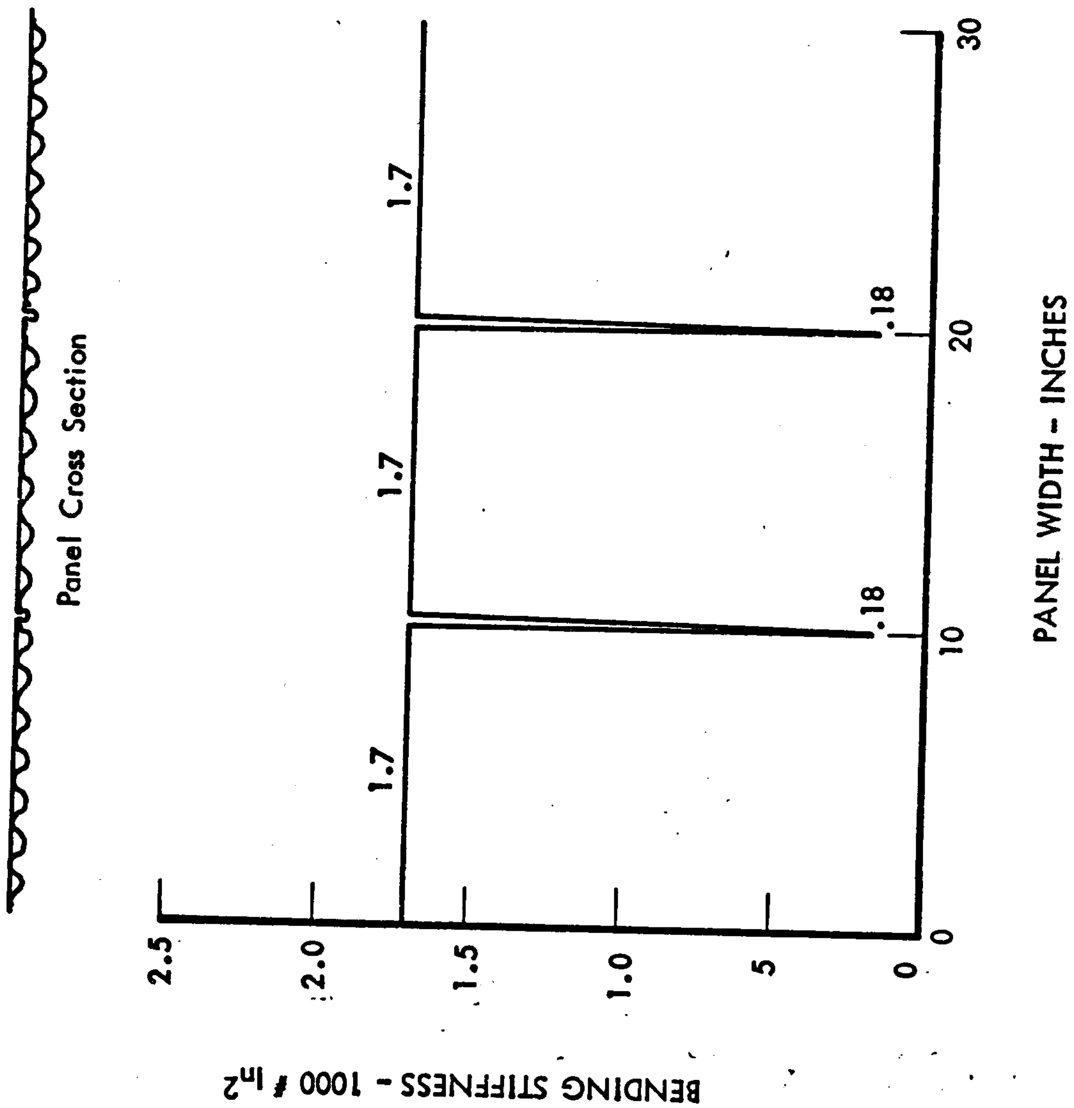


Figure 3-37: CHORDWISE CENTER PANEL BENDING STIFFNESS

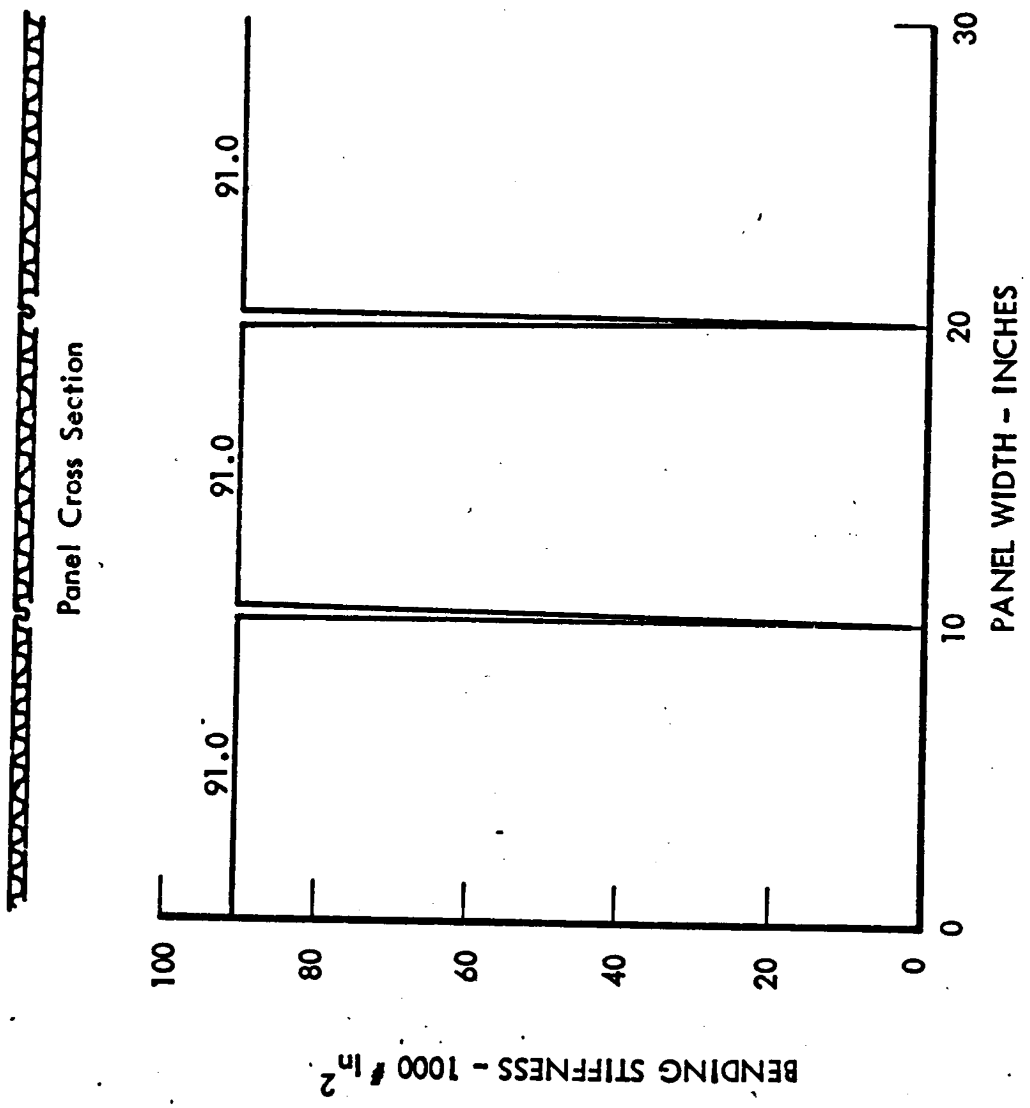


Figure 3-38: CHORDWISE EDGE PANEL BENDING

3.3.2 Standoff Spring Constants

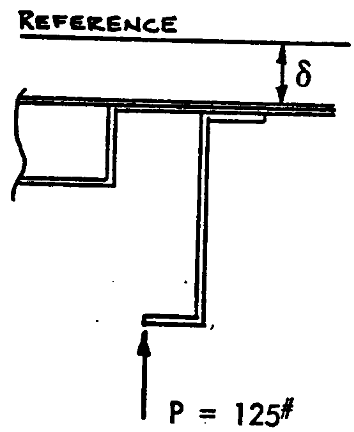
Deflection stiffness of the support clip was obtained from computer output. This was done by uniformily loading a panel section which resulted in a deflection of a point over the clip and a clip reaction. These were used to compute the deflection stiffness as shown below:

$$K = \frac{P}{\delta}$$

$P = 125^{\#}$ Reaction/Clip

$= 0.00268$ In Deflection

$K = -5040\ ^{\#}/\text{In}$



The torsional stiffness of the support clip is computed below:

$$K_T = \frac{T}{\theta} = \frac{GJ}{\ell}$$

$\ell_1 = .25$ In

$\ell_2 = .25$ In

$b = 1.00$ In

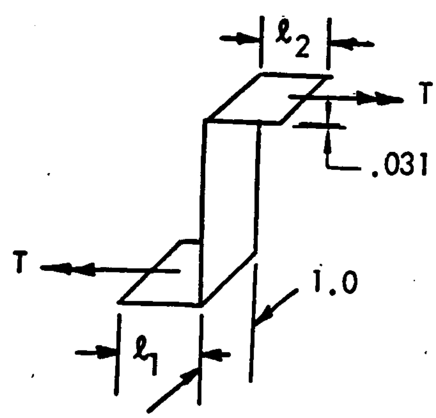
$t = .031$ In

$J = \frac{1}{3} bt^3$

$= 9.93 \times 10^{-6}\ \text{In}^4$

$G = 11 \times 10^6$ Psi

$\ell = \ell_1 + \ell_2 = .50$ In



$$K_T = \frac{(11. \times 10^6)(9.93 \times 10^{-6})}{(.50)} = 218\ \text{In-}^{\#}/\text{Rad}$$

The rotational stiffness of the support clip is computed below:

$$K_R = \frac{M}{\theta} = \frac{EI}{\ell}$$

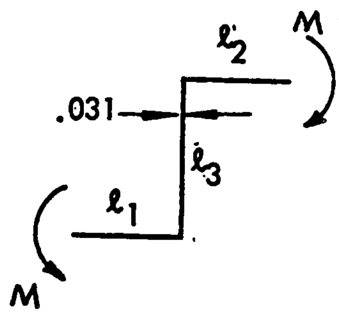
$\ell_1 = .25$ In

$\ell_2 = .25$ In

$\ell_3 = 2.00$ In

$b = 1.00$ In

$t = .031$ In



$$I = \frac{1}{12} bt^3$$

$$= 2.48 \times 10^{-6} \text{ In}^4$$

$$E = 29 \times 10^6 \text{ Psi}$$

$$\ell = \ell_1 + \ell_2 + \ell_3 = 2.50 \text{ In}$$

$$K_R = \frac{(29 \times 10^6)(2.48 \times 10^{-6})}{2.50} = 28.8 \text{ In-\#/Rad}$$

It should be noted that these stiffnesses do not reflect edge member effects at corrugation ends.

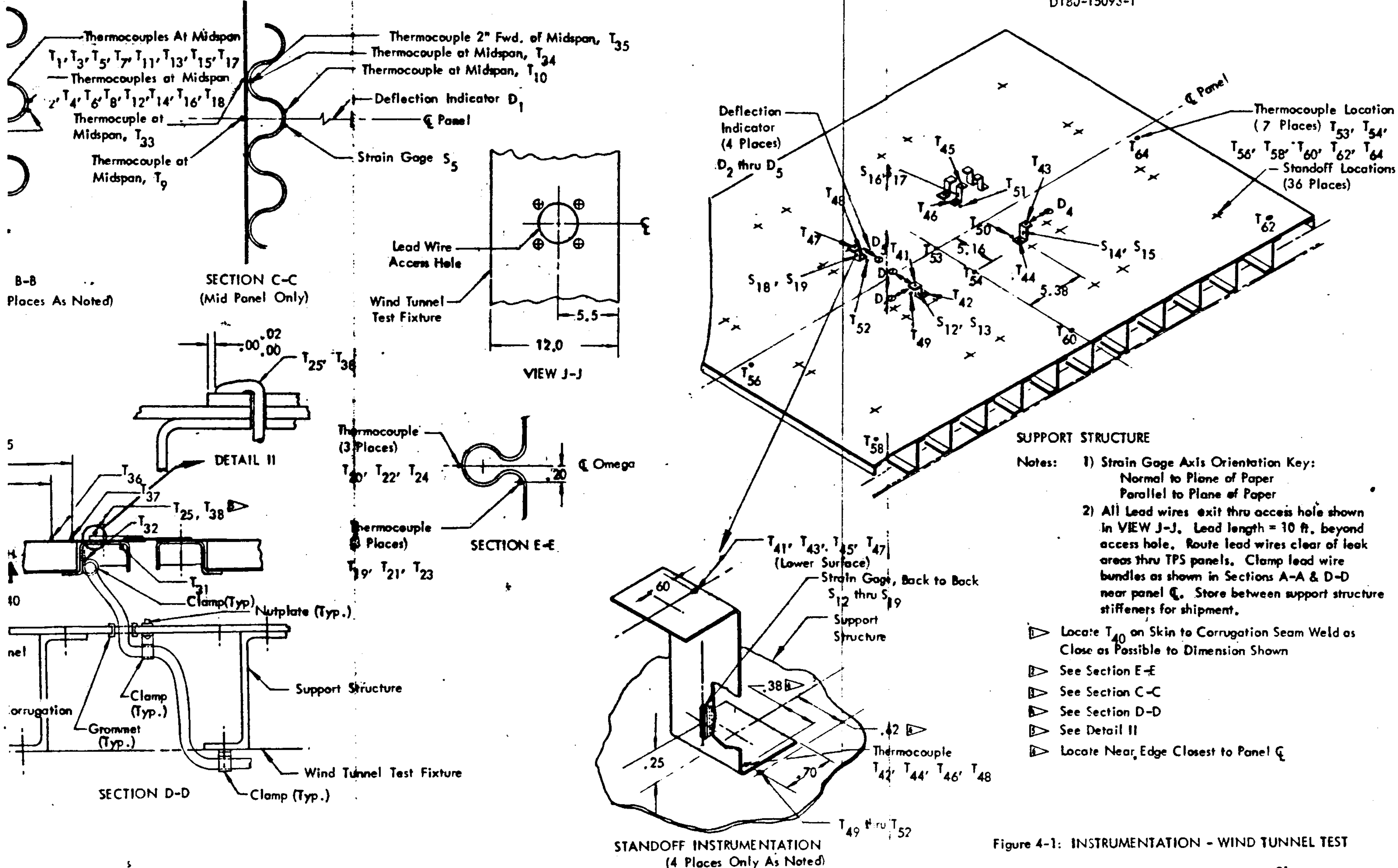
4.0 TEST ARTICLE INSTRUMENTATION

4.1 Wind Tunnel Test Article

4.1.1 Instrumentation Installation

The instrumentation installed for the Wind Tunnel Test is defined in Figure 4-1. The center TPS panel segment is fully instrumented to define panel thermal, stress and deflection characteristics. The other eight segments are each instrumented with two thermocouples (skin and corrugation) and one strain gage (corrugation) to provide additional data regarding (a) thermal gradients across the full TPS panel arrangement, and (b) edge effects from the test fixture. Thermocouples are used extensively to establish thermal gradients across and through the TPS panels, as well as along the "Z" section, omega seal, the attachment clips and the support structure. All thermocouples and their leads are located internally out of the plasma flow wherever possible. Prior to high temperature runs (in excess of 600°F) the strain gages on the corrugations will provide stress data at this critical location. Strain gages on the four clips attaching the center segment panel will determine bending stresses in the clip vertical leg. Panel thermal growth will be determined on the center panel segment from the deflection measuring devices monitoring bowing at the ℄ of the panel, and from deflection measuring devices checking the deflection of three attachment clips.

Since the support structure approximates the heat sink of the vehicle substrate structure, the thermocouples on the support structure will verify substrate structure

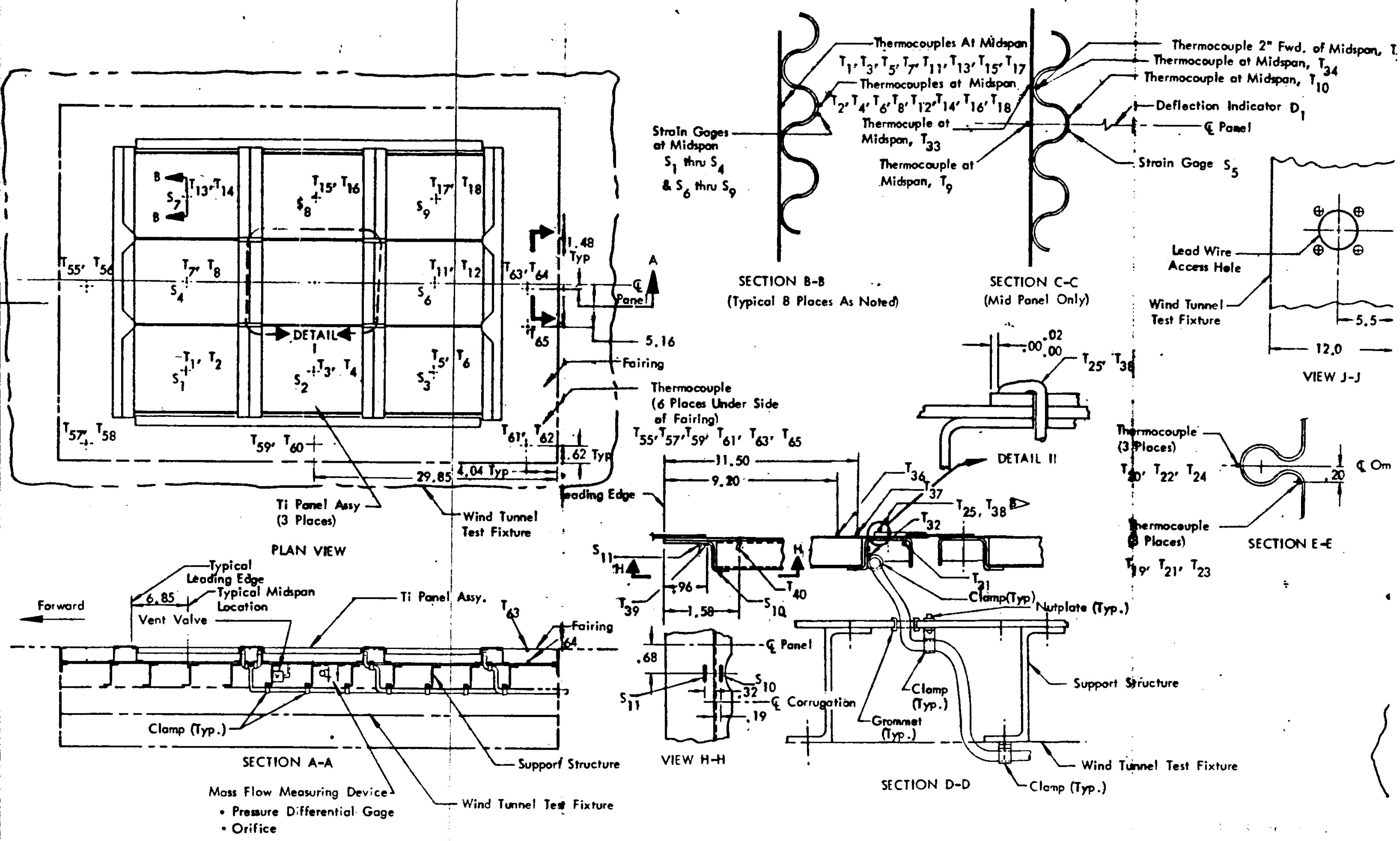


SUPPORT STRUCTURE

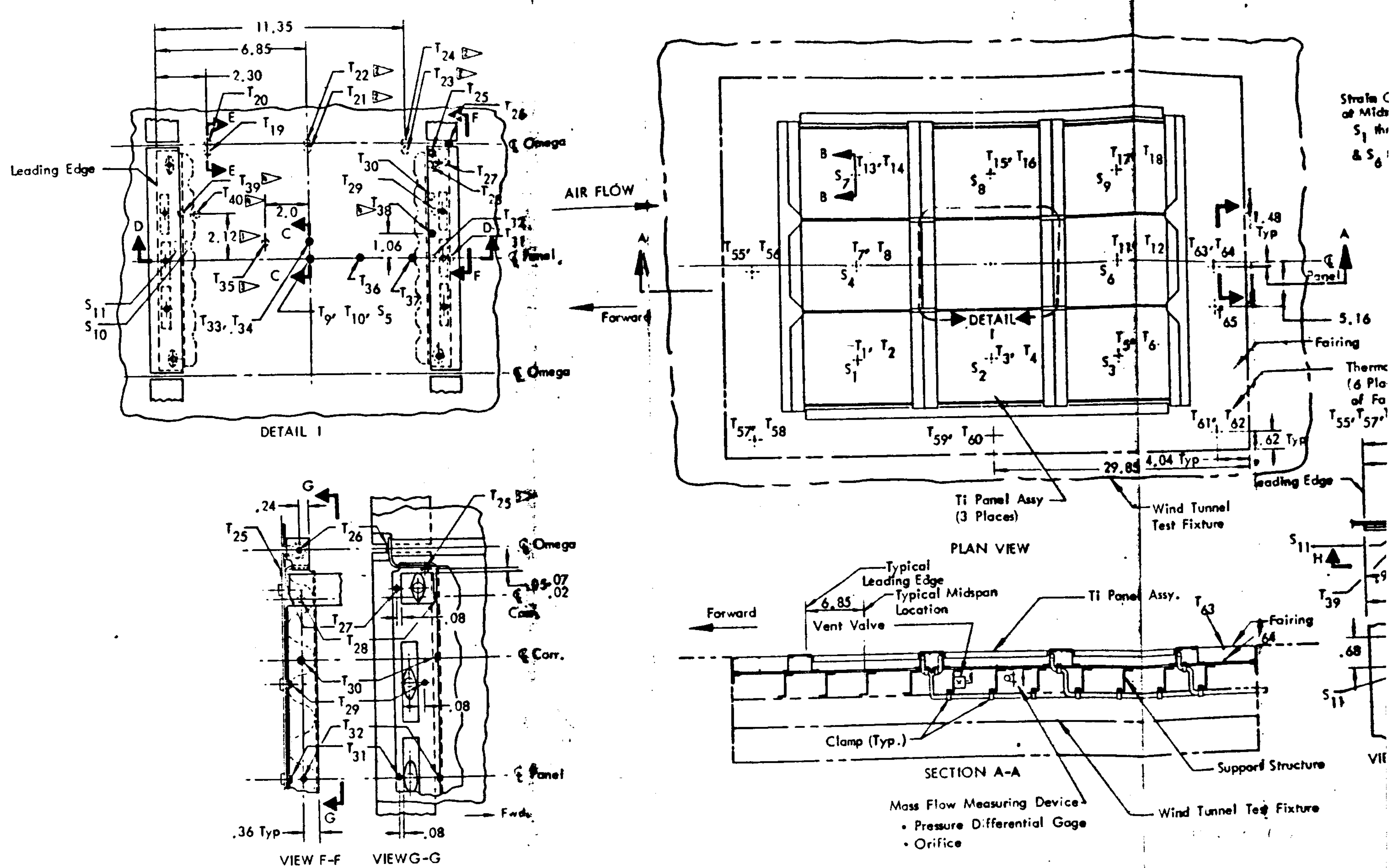
Notes:
1) Strain Gage Axis Orientation Key:
   Normal to Plane of Paper
   Parallel to Plane of Paper
2) All Lead wires exit thru access hole shown in VIEW J-J. Lead length = 10 ft. beyond access hole. Route lead wires clear of leak areas thru TPS panels. Clamp lead wire bundles as shown in Sections A-A & D-D near panel ℄. Store between support structure stiffeners for shipment.

1 ▷ Locate T_{40} on Skin to Corrugation Seam Weld as Close as Possible to Dimension Shown
2 ▷ See Section E-E
3 ▷ See Section C-C
4 ▷ See Section D-D
5 ▷ See Detail 11
6 ▷ Locate Near Edge Closest to Panel ℄

Figure 4-1: INSTRUMENTATION - WIND TUNNEL TEST



PLAN VIEW
DETAIL I
Ti Panel Assy
(3 Places)
Wind Tunnel
Test Fixture
Fairing
Thermocouple
(6 Places Under Side
of Fairing)
$T_{55}, T_{57}, T_{59}, T_{61}, T_{63}, T_{65}$
29.85
4.04 Typ
.62 Typ
1.48
Typ
5.16
℄ Panel
SECTION B-B
(Typical 8 Places As Noted)
Thermocouples At Midspan
$T_1, T_3, T_5, T_7, T_{11}, T_{13}, T_{15}, T_{17}$
Thermocouples at Midspan
$T_2, T_4, T_6, T_8, T_{12}, T_{14}, T_{16}, T_{18}$
Strain Gages
at Midspan
S_1 thru S_4
& S_6 thru S_9
SECTION C-C
(Mid Panel Only)
Thermocouple 2" Fwd. of Midspan, T
Thermocouple at Midspan, T_{34}
Thermocouple at Midspan, T_{10}
Deflection Indicator D_1
℄ Panel
Strain Gage S_5
Thermocouple at
Midspan, T_{33}
Thermocouple at
Midspan, T_9
VIEW J-J
Lead Wire
Access Hole
Wind Tunnel
Test Fixture
5.5
12.0
DETAIL II
SECTION E-E
Thermocouple
(3 Places)
T_{20}, T_{22}, T_{24}
Thermocouple
(3 Places)
T_{19}, T_{21}, T_{23}
℄ Om
.20
Leading Edge
11.50
9.20
.96
1.58
S_{10}
S_{11}
T_{39}
T_{40}
VIEW H-H
.68
.32
.19
℄ Panel
℄ Corrugation
SECTION D-D
Clamp (Typ)
Nutplate (Typ.)
Clamp
(Typ.)
Grommet
(Typ.)
Support Structure
Wind Tunnel Test Fixture
Clamp (Typ.)
SECTION A-A
Forward
Typical
Leading Edge
Typical Midspan
Location
6.85
Vent Valve
Ti Panel Assy.
Fairing
Clamp (Typ.)
Support Structure
Wind Tunnel Test Fixture
Mass Flow Measuring Device
• Pressure Differential Gage
• Orifice



Leading Edge
11.35
6.85
2.30
2.0
2.12
1.06
DETAIL I
AIR FLOW
Forward
€ Omega
€ Panel
PLAN VIEW
Ti Panel Assy
(3 Places)
Wind Tunnel
Test Fixture
29.85
4.04 Typ
.62 Typ
1.48
Typ
5.16
Fairing
VIEW F-F
VIEW G-G
.24
.36 Typ
.08
€ Corr.
Fwd
SECTION A-A
Typical
Leading Edge
6.85
Typical Midspan
Location
Vent Valve
Ti Panel Assy.
Clamp (Typ.)
Support Structure
Wind Tunnel Test Fixture
Mass Flow Measuring Device
• Pressure Differential Gage
• Orifice

temperature predictions. In addition, registering of unduly high temperatures on the support structure by any thermocouple will aid in pinpointing TPS panel seal and joint areas which permit excessive plasma flow passage.

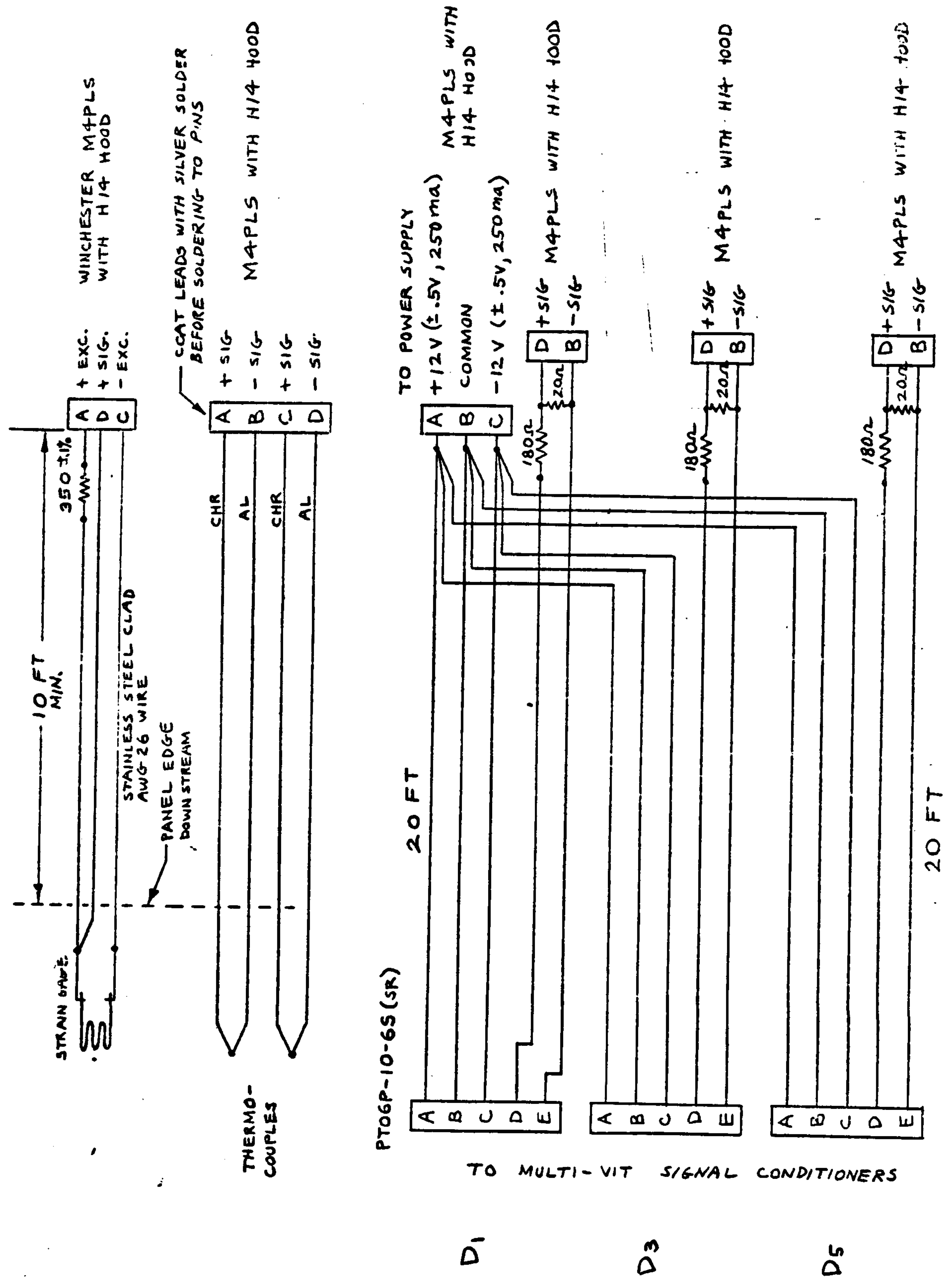
Following discussions with the contract monitor, initial plans to measure gross plasma leakage through panel seals and joints have been abandoned. This was to be accomplished by using pressure gages and thermocouples to measure gas flow through an orifice mounted on the support structure skin. The local tunnel pressure outside the TPS panels was estimated to be .8 psi. However, subsequent analyses to define the tunnel environment required to provide the correct temperature profile for the panels (See Section 5.1) indicates that the nominal local pressure will be approximately .175 psi external to the panels and .120 psi inside the cavity of the test panel holder. Consequently, the differential pressure available for measuring gas flow, without unduly restricting gas leakage, is too low to provide a sufficiently accurate measurement. Therefore, no instrumentation has been provided for this purpose.

Results obtained from this test by evaluation of instrumentation data and examination of the test specimen will serve in evaluating the suitability of this TPS design for the Space Shuttle mission. The temperature distributions measured throughout the specimen, including local discontinuities, will verify the analytical methods that will be used for final TPS design. Determination of the thermal growth of the panels will assist in establishing the functional adequacy of the joints and seals. It will also assist in establishing adequacy of the seals, standoff clips, and "Z" edge member, and basic panel structure by verifying analytical results.

Assessment of the overall structural integrity of the TPS design will provide confidence that the proposed configuration will survive the Space Shuttle environment. In addition, it will assist in establishing that the TPS design will survive for 100 missions or in defining the required refurbishment. In addition to verifying the adequacy of the basic panel and standoff clips, the adequacy of the following details will be verified: 1) the omega seal and associated end plates which are an integral part of the design, and 2) the joint seals.

4.1.2 Calibration Data

Calibration data for all instrumentation installed on the Wind Tunnel Test Article is shown in Figures 4-2 through 4-7.

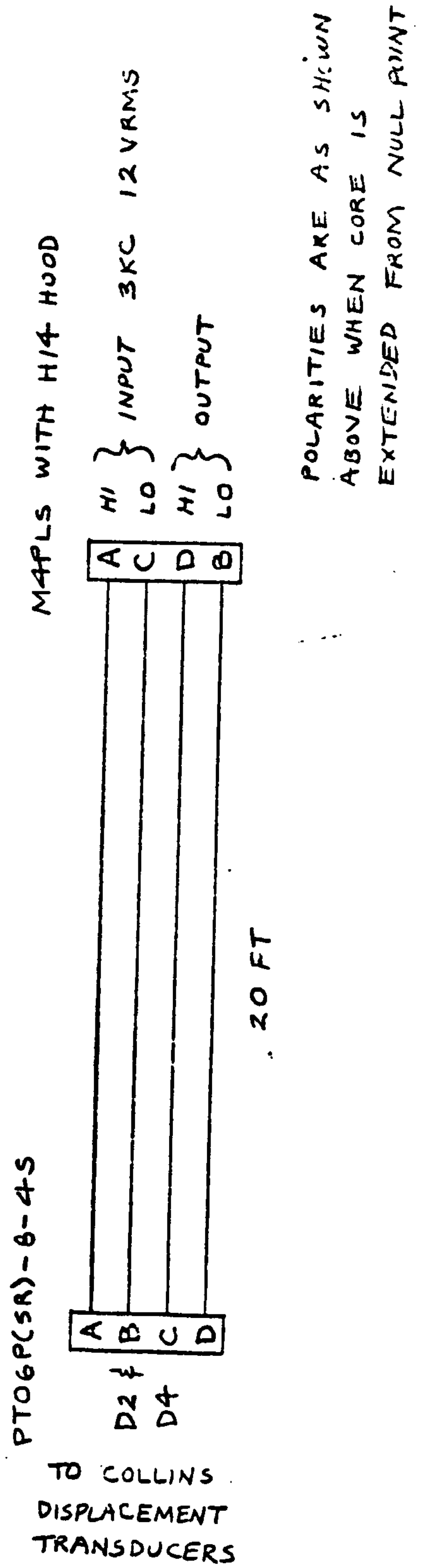


CALC	Y. S.	5/18/72	REVISED	DATE	CANDIDATE S/S TPS PANEL WIND TUNNEL TEST INSTRUMENTATION WIRING	Figure 4-2
CHECK						
APR	NDR	7/13/72				
APR					THE BOEING COMPANY RENTON, WASHINGTON	PAGE 1

TD 1017-R8

Figure 4-2

6-7000



CALC	Y.S.	5/18/72	REVISED	DATE	CANDIDATE S/S TPS PANEL WIND TUNNEL TEST INSTRUMENTATION WIRING	
CHECK			Y.S.	6/15/72		
APR	[illegible]	7/15/72				Figure 4-3
APR					THE BOEING COMPANY RENTON, WASHINGTON	PAGE 2

TD 1017-RS

Figure 4-3

6-7000

MEASUREMENT I.D.	CONNECTOR I.D.	CONNECTOR PIN NO.S	SENSITIVITY	REMARKS
T1	TC1	A-B	CHROMEL-ALUMEL I.S.A. TYPE K CALIBRATION	
T2	TC1	C-D		
T3	TC2	A-B		
T4	TC2	C-D		
T5	TC3	A-B		
T6	TC3	C-D		
T7	TC4	A-B		
T8	TC4	C-D		
T9	TC5	A-B		
T10	TC5	C-D		
T11	TC6	A-B		
T12	TC6	C-D		
T13	TC7	A-B		
T14	TC7	C-D		
T15	TC8	A-B		
T16	TC8	C-D		
T17	TC9	A-B		
T18	TC9	C-D		
T19	TC10	A-B		
T20	TC10	C-D		
T21	TC11	A-B		
T22	TC11	C-D		
T23	TC12	A-B		
T24	TC12	C-D		
T25	TC13	A-B		
T26	TC13	C-D		
T27	TC14	A-B		
T28	TC14	C-D		
T29	TC15	A-B		
T30	TC15	C-D		
T31	TC16	A-B		
T32	TC16	C-D		
T33	TC17	A-B		
T34	TC17	C-D		
T35	TC18	A-B		
T36	TC18	C-D		
T37	TC19	A-B		
T38	TC19	C-D		
T39	TC20	A-B		
T40	TC20	C-D		
T41	TC21	A-B		
T42	TC21	C-D		
T43	TC22	A-B		
T44	TC22	C-D		
T45	TC23	A-B		
T46	TC23	C-D		
T47	TC24	A-B		
T48	TC24	C-D		
T49	TC25	A-B		
T50	TC25	C-D		
T51	TC26	A-B		
T52	TC26	C-D		
T53	TC27	A-B		
T54	TC27	C-D		
T55	TC28	A-B		
T56	TC28	C-D		
T57	TC29	A-B		
T58	TC29	C-D		
T59	TC30	A-B		
T60	TC30	C-D		
T61	TC31	A-B		
T62	TC31	C-D		
T63	TC32	A-B		
T64	TC32	C-D		
T65	TC33	A-B		

7-13-72
7-13-72

CANDIDATE S/S TPS PANEL - WIND TUNNEL TEST

Figure 4-4

MEASUREMENT I.D.	CONNECTOR I.D.	CONNECTOR PIN NO.'s	SENSITIVITY	REMARKS
S1	S1	▷1	R = 350 Ω ± .3% K = 2.0 ± 1.0% Kt = -2.5%	STRAIN GAGE WK-05-125BT-350
S2	S2			
S3	S3			
S4	S4			
S5	S5			
S6	S6			
S7	S7			
S8	S8			
S9	S9			
S10	S10			
S11	S11			
S12	S12			
S13	S13			
S14	S14			
S15	S15			
S16	S16			
S17	S17			
S18	S18			
S19	S19	▷1		
D1	D1	▷1	200 mV/INCH	PRELOAD .30 IN ±.25 IN RANGE
D2	D2	▷2	▷3	
D3	D3	▷1	1000 mV/INCH	PRELOAD .06 IN ±.05 IN RANGE
D4	D4	▷2	▷3	
D5	D5	▷1	1000 mV/INCH	PRELOAD .06 IN ±.05 IN RANGE

▷1 WIRE PER SHT 1

▷2 WIRE PER SHT 2

▷3 CALIBRATE IN PLACE USING AVAILABLE CARRIER AMPLIFIER SEE SHEET 2 FOR WIRING

CANDIDATE S/S TPS PANEL - WIND TUNNEL TEST

Figure 4-5

SHEET 4

G. L. C[illegible] CORPORATION
5875 Obispo Aven[illegible] Long Beach, California

Inspection by -060-

Approved by

Date [illegible] '72

Part No. LMB-181C15 S/N 70608
Env. Conditions: RT

VISUAL & MECH. INSPECTION:

DIAM: Case ✓ Core ✓ Probe ✓
LENGTH: Case ✓ Core ✓ Probe ✓
OBSERVED DEFECTS: NONE

INSULATION BREAKDOWN: (500 Volts DC)

PRI-SEC: ☑ O.K. ☐ Failed
PRI-CASE: ☑ O.K. ☐ Failed
SEC-CASE: ☑ O.K. ☐ Failed

EXCITATION: Voltage 6V Freq. 400 ~
WATTS: Input — Load —
RESISTANCE: Pri — Sec —

POLARITY: ☑ O.K. ☐ Reversed

NULL VOLTAGE 2.9MV POSITION OK

LINEARITY 0.22 % F.S.

SCALE FACTOR 2.250 V/IN/V

PHASE SHIFT (-0- Max.) — Deg.

RDG.	POSITION (Inches)	RATIO XFMR RDG. (E_o/E_i)	Δ R.T.	DEVIATION RDG.	PHASE SHIFT -0-
+5	.25	5640			
+4	.20	4530	1110		
+3	.15	3390	1140		
+2	.10	2270	1120		
+1	.05	1140	1130		
0	0	0	1140		90°
-1	.05	1140	1140		
-2	.10	2260	1120		
-3	.15	3370	1110		
-4	.20	4500	1130		
-5	.25	5600	1100		
		TOTAL			

D2

REMARKS

FINAL CHECK - OK

Figure 4-6: INSTRUMENTATION - VENDOR CALIBRATION DATA-D2

LM6-0001-1

G. L. [illegible] CORPORATION
5875 Obispo Ave [illegible] Long Beach, California

Date [illegible] 6 1972

Inspection by -060-
Approved by

Part No. LHB-131C15 S/N 95161
Env. Conditions: RT

VISUAL & MECH. INSPECTION:

DIAM: Case ✓ Core ✓ Probe ✓
LENGTH: Case ✓ Core ✓ Probe ✓
OBSERVED DEFECTS: NONE

INSULATION BREAKDOWN: (500 Volts DC)

PRI-SEC: ☑ O.K. ☐ Failed
PRI-CASE: ☑ O.K. ☐ Failed
SEC-CASE: ☑ O.K. ☐ Failed

EXCITATION: Voltage 6 V Freq. 1100 N
WATTS: Input — Load 0
RESISTANCE: Pri Sec —

POLARITY: ☑ O.K. ☐ Reversed
NULL VOLTAGE 3 MV POSITION OK
LINEARITY 0.111 % F.S.
SCALE FACTOR 2.2112 V/IN/V
PHASE SHIFT (-0- Max.) — Deg.

RDG.	POSITION (Inches)	RATIO XFMR RDG. (E_o/E_i)	Δ R.T.	DEVIATION RDG.	PHASE SHIFT -0-
+5	.25	5620			
+4	.20	4500	1120		
+3	.15	3380	1120		
+2	.10	2250	1130		
+1	.05	1130	1120		
0	0	0	1130		90°
-1	.05	1130	1130		
-2	.10	2250	1130		
-3	.15	3370	1120		
-4	.20	4490	11[illegible]0		
-5	.25	5590	1100		
		TOTAL			

D4

REMARKS

FINAL CHECK - OK

Figure 4-7: INSTRUMENTATION - VENDOR CALIBRATION DATA-D4

4.2 Sonic Fatigue Test Article

4.2.1 Instrumentation Installation

The instrumentation installed for the Sonic Fatigue Test is defined in Figure 4-8. Stress distribution is determined primarily in the center panel segment which has strain gages and thermocouples on the skin, corrugation, "Z" section and four support clips. Four adjacent panels also have strain gages and thermocouples on the skin and corrugation in order to compare response of these panels to that of the center panel. The four remaining panels have thermocouples only on the skin and corrugation. These will show panel temperature variations resulting from edge effects.

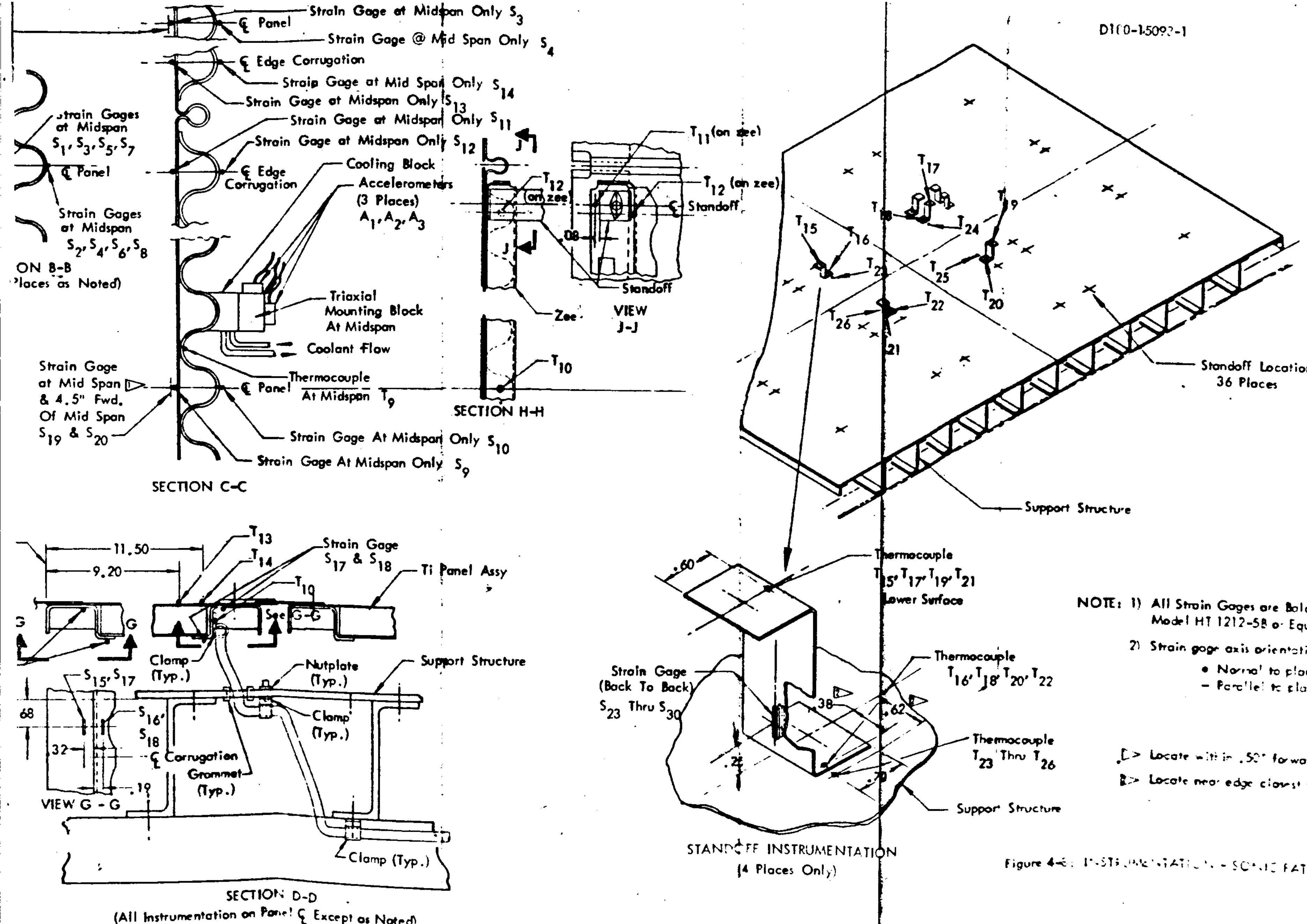
Two tri-axial accelerometers are mounted to the corrugation on the center segment. One is located at the center and one adjacent to one attachment clip. This arrangement should provide the maximum panel acceleration data. Micro-miniature accelerometer similar to the Endevco Model 2222B which have the replaceable cables are used. These are arranged triaxially on a mounting block, which in turn is attached to a cooling block fixed to the corrugation. This arrangement, less cables and mounting bolts, meets the contract requirement that the weight not exceed 4.5 grams.

Provisions are also made in the enclosure skin, at the ℄ of panels, for a 1/4 inch diameter Bruel and Kjaer microphone.

Data derived from this test will assist in verifying structural integrity of the TPS panel under the acoustic environment. Panel structural weaknesses, if any, can be determined and corrective action taken.

4.2.2 Calibration Data

Calibration data for all instrumentation installed on the Sonic Fatigue Test Article is shown in Figure 4-9.



NOTE: 1) All Strain Gages are Baldwin/Lima/Hamilton Model HT 1212-58 or Equivalent.

2) Strain gage axis orientation key:

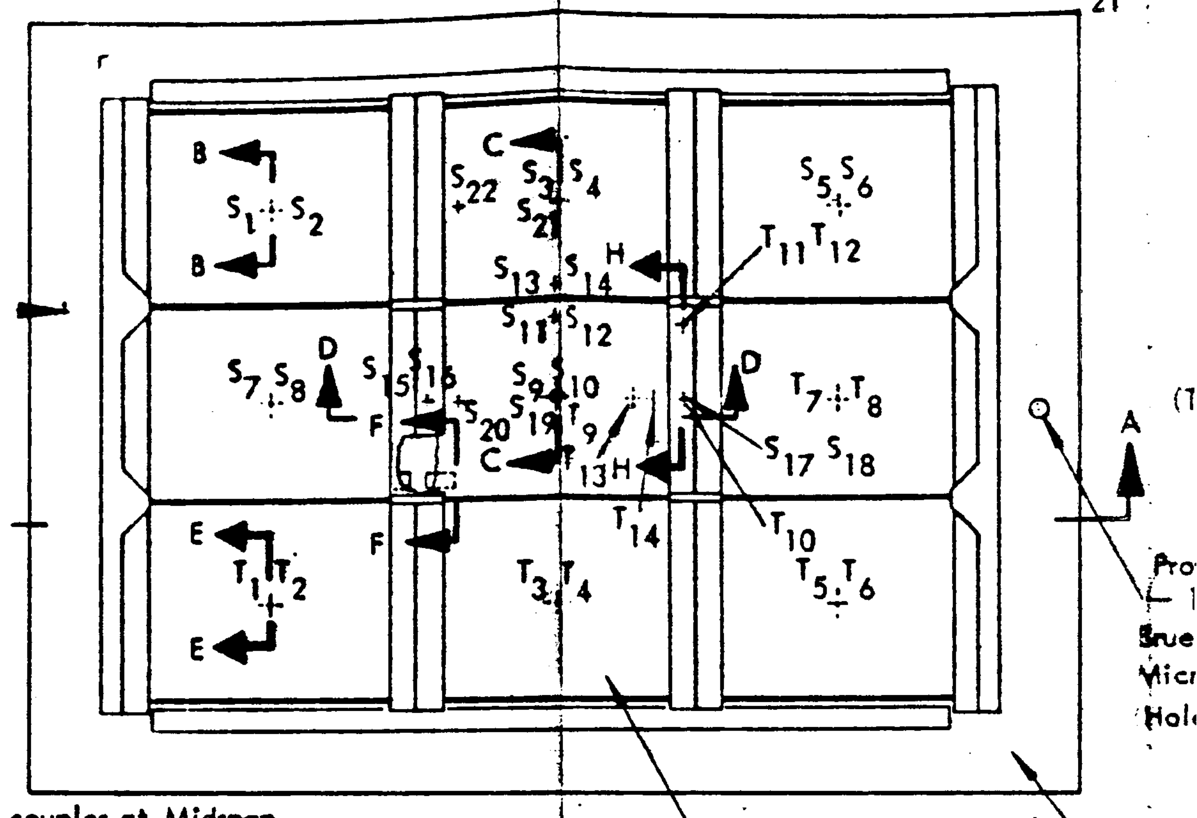
- • Normal to plane of paper
- – Parallel to plane of paper

⊳ Locate within .50" forward of S_3 or S_9

⊳ Locate near edge closest to panel ℄

Figure 4-6: INSTRUMENTATION - SONIC FATIGUE TEST

Mid Span
4.5" Fwd.
Mid Span
S_{21} & S



couples at Midspan

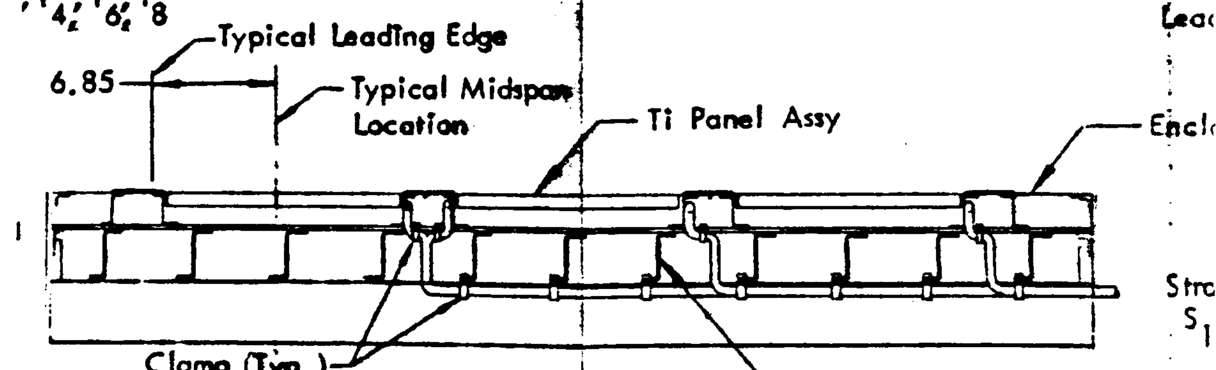
3, T_7

PLAN VIEW

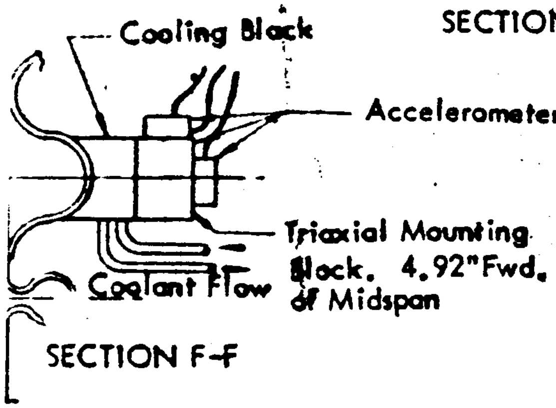
Ti Panel Assy
3 Places

rmocouples at Midspan

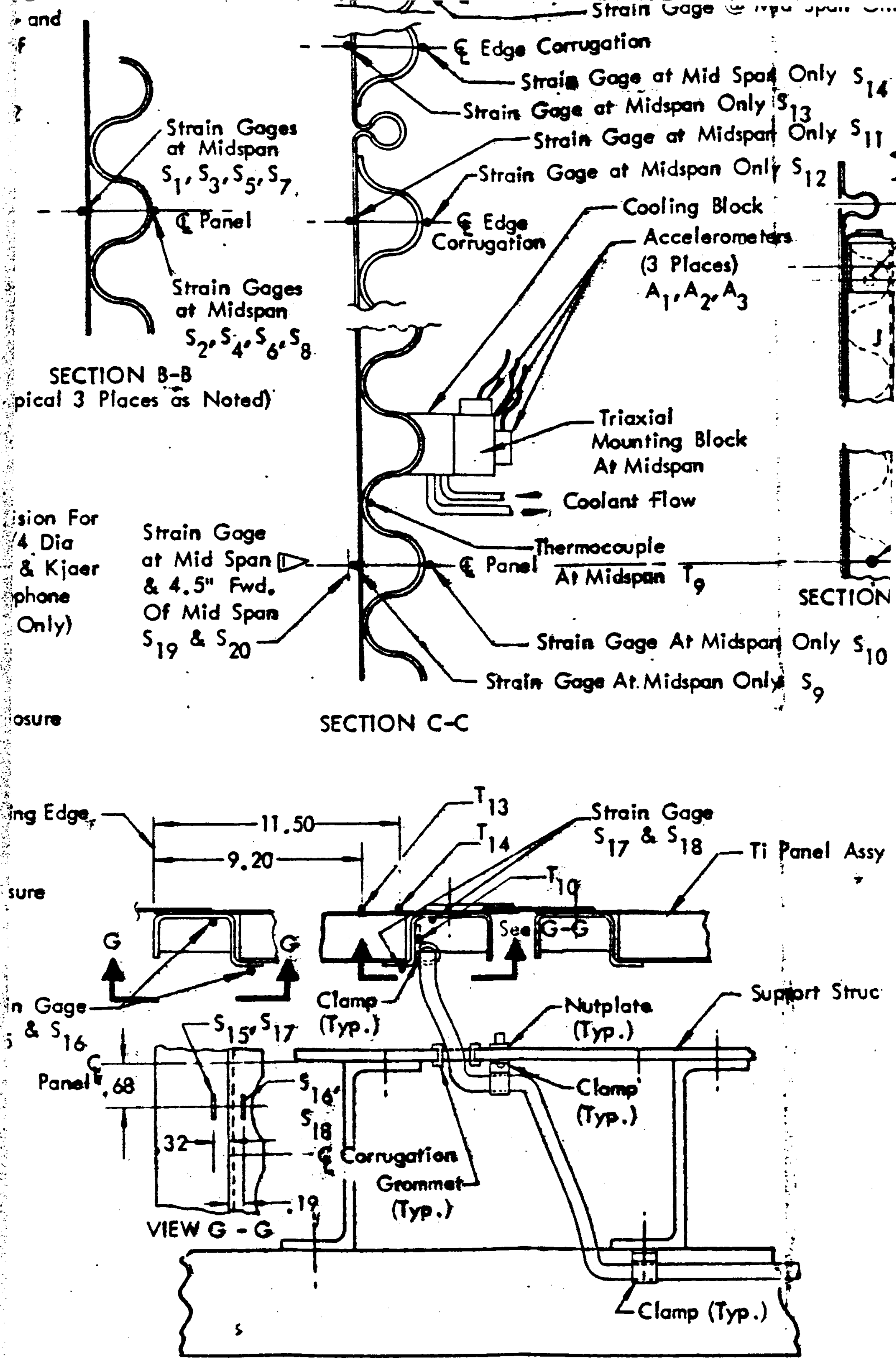
, T_4, T_6, T_8



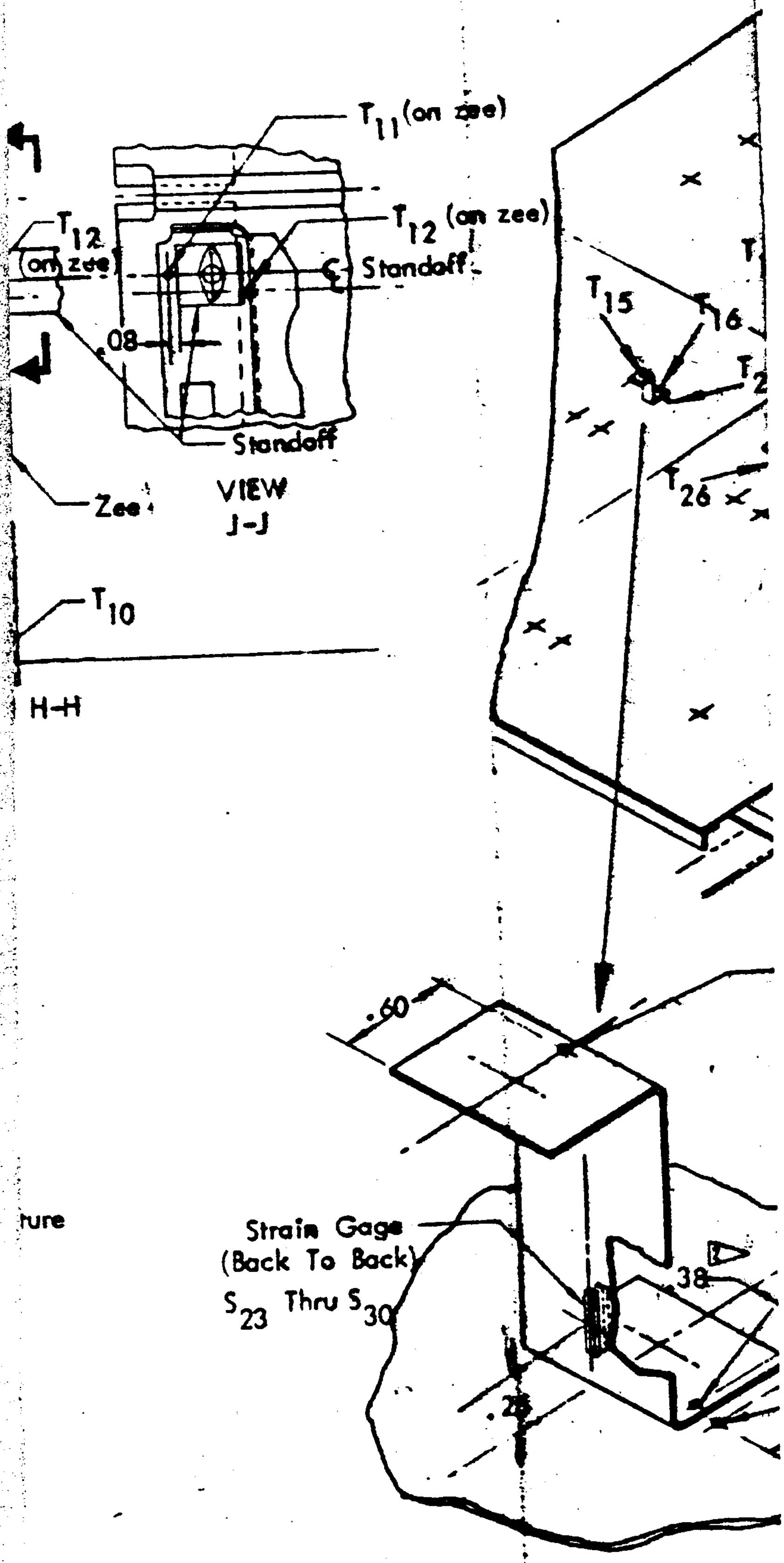
SECTION A-A



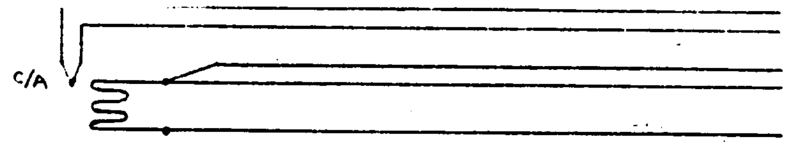
SECTION F-F



SECTION D-D
(All Instrumentation on Panel ℄ Except as Noted)



STANDOFF INSTRUMENTA
(4 Places Only)



STRAIN GAGE WIRING

HT 1212-5A
120 ± 1.0 Ω
K = 4.11

THERMOCOUPLES — CHROMEL-ALUMEL
ISA TYPE K CALIBRATION

ACCELEROMETERS - ENDEVCO 2222B

MEASUREMENT NO.	S/N	SENSITIVITY Pc/G
A1	AB35	1.22
A2	AC05	1.38
A3	AC61	1.12
A4	BE12	1.31
A5	BE31	1.23
A6	BE40	1.40

S/S THERMAL PROTECTION SYSTEM
SONIC TEST PANEL INSTRUMENTATION

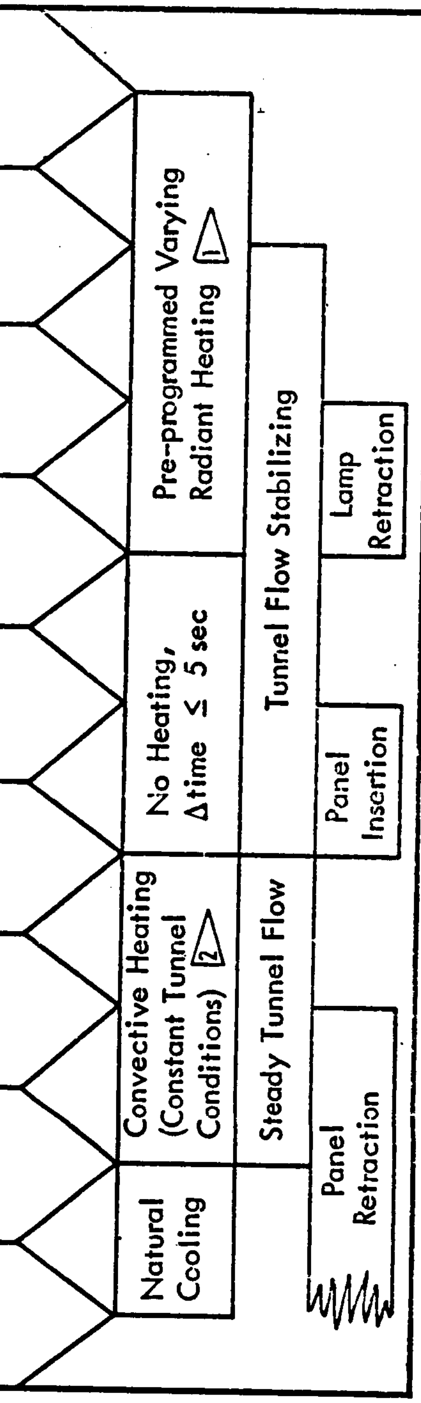
y8 7-13-72

5.0 RECOMMENDED TEST CONDITIONS

5.1 Wind Tunnel Test

The recommended test sequence is shown in Figure 5-1. The sequence consists of a pre-programmed radiant heating cycle followed immediately by insertion of the panel into a stabilized flow of tunnel gases. The estimated time of occurrence for each event is also shown together with the recommended nominal tunnel operating conditions. The resulting nominal environment is shown in Figures 5-2 and 5-3. The corresponding design flight environment is shown in Figure 5-4. In order not to over-shoot the design environment it is recommended that the test run sequence shown in Figure 5-5 be followed. The first five runs would be used to verify that the calculated nominal conditions are correct or to revise them if necessary.

TIME, SEC	EVENT	DESCRIPTION
0	1	Initiate radiant heating
As req'd for Event 6 (340 [3])	2	Pump down, start tunnel
As req'd for Event 4 (345 [3])	3	Initiate radiant lamp retraction
348 [3]	4	End radiant heating
As req'd for Event 6 (348 [3])	5	Initiate panel injection
350	6	Panel in tunnel flow core
As req'd for Event 8 (390 [3])	7	Initiate panel retraction
390	8	End convective heating
800	9	End data acquisition



[1] See plot of panel temperature history to be achieved by varying radiant heat input

[2] Tunnel Conditions: P_t = 1000 psi
T_t = 2500° R
α = 2.5° (tentative)

[3] Estimated

Figure 5-1: PROPOSED TEST SEQUENCE

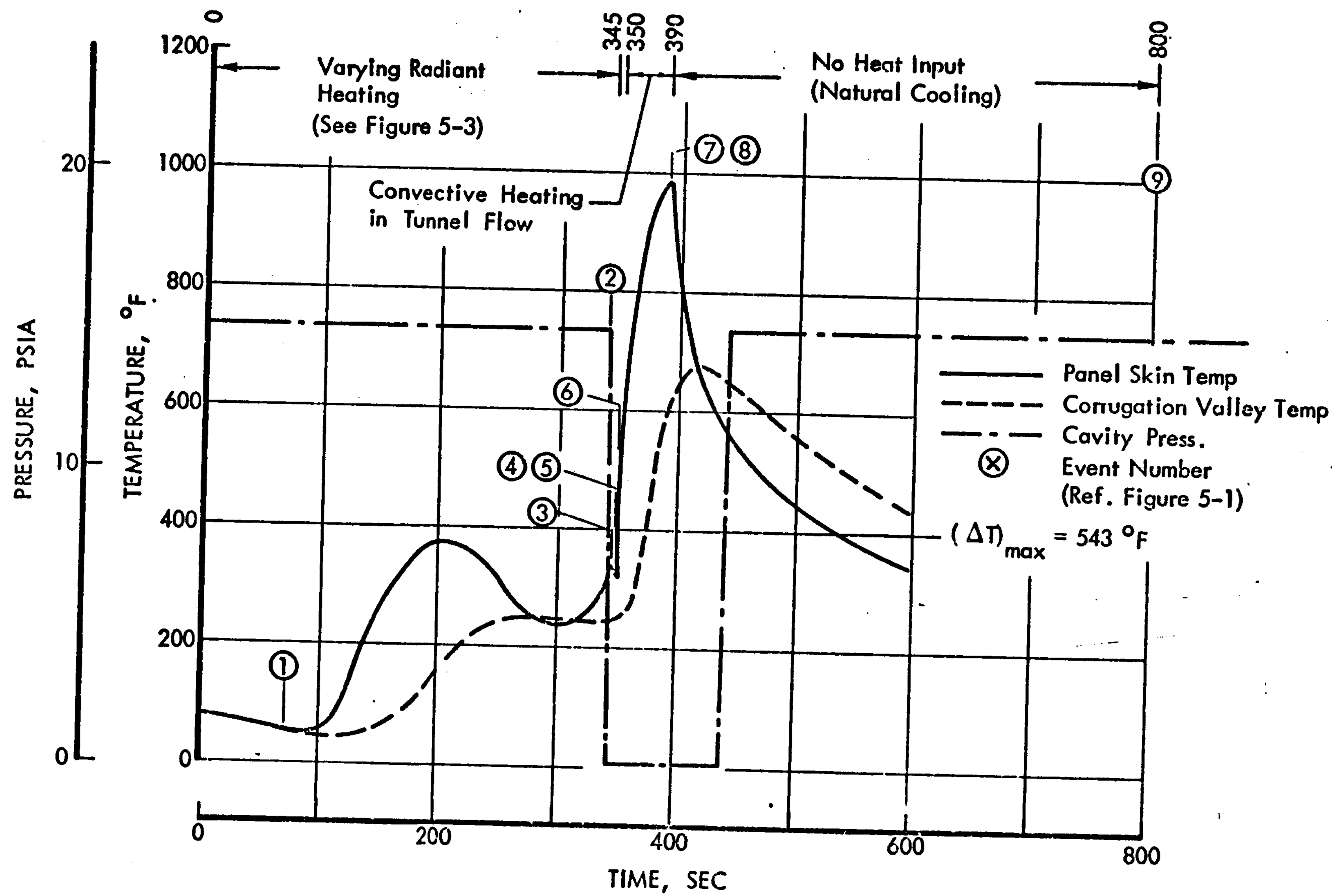


Figure 5-2: PROPOSED TEST ENVIRONMENT - WIND TUNNEL TEST

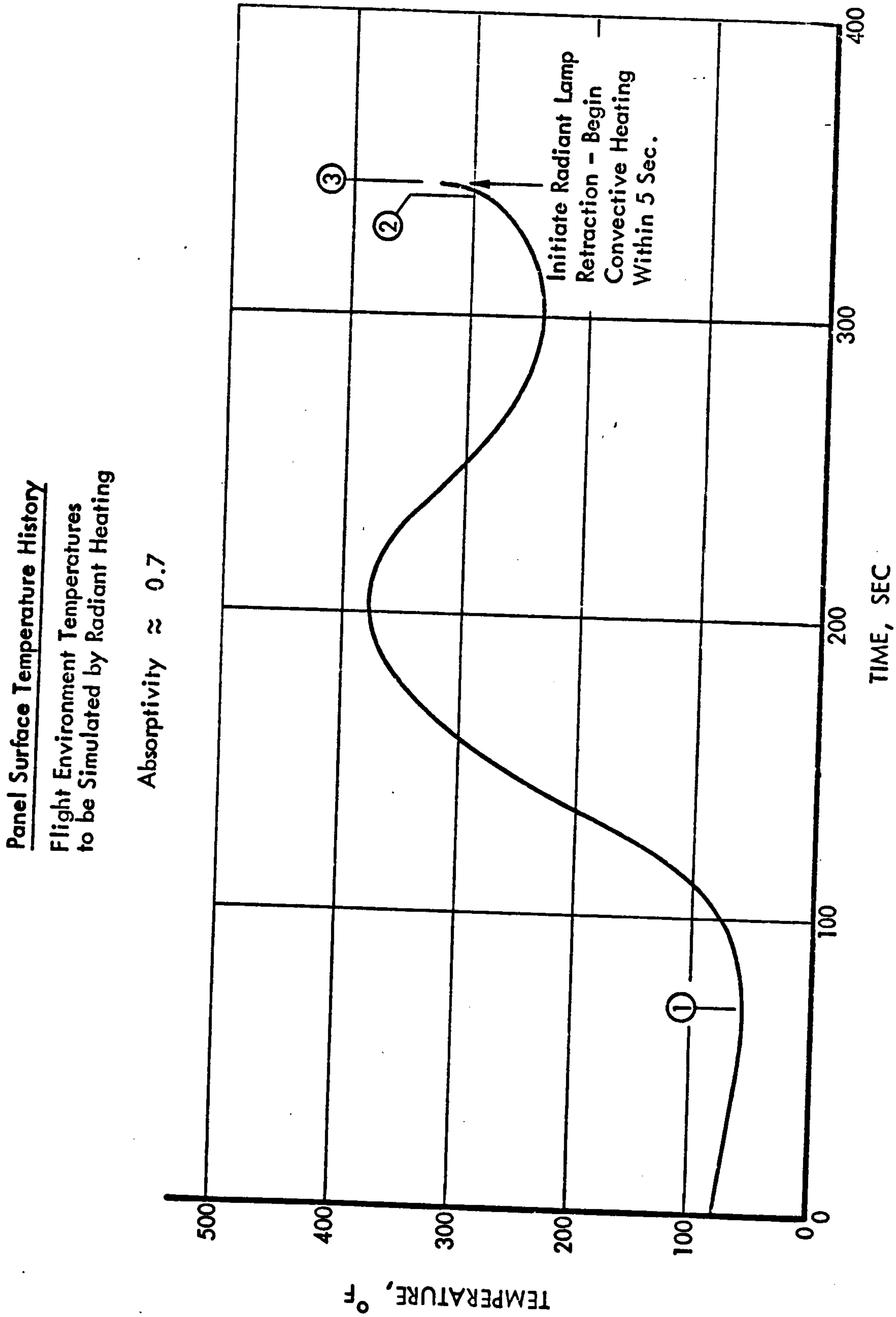


Figure 5-3: PROPOSED TEST ENVIRONMENT - RADIANT HEATING

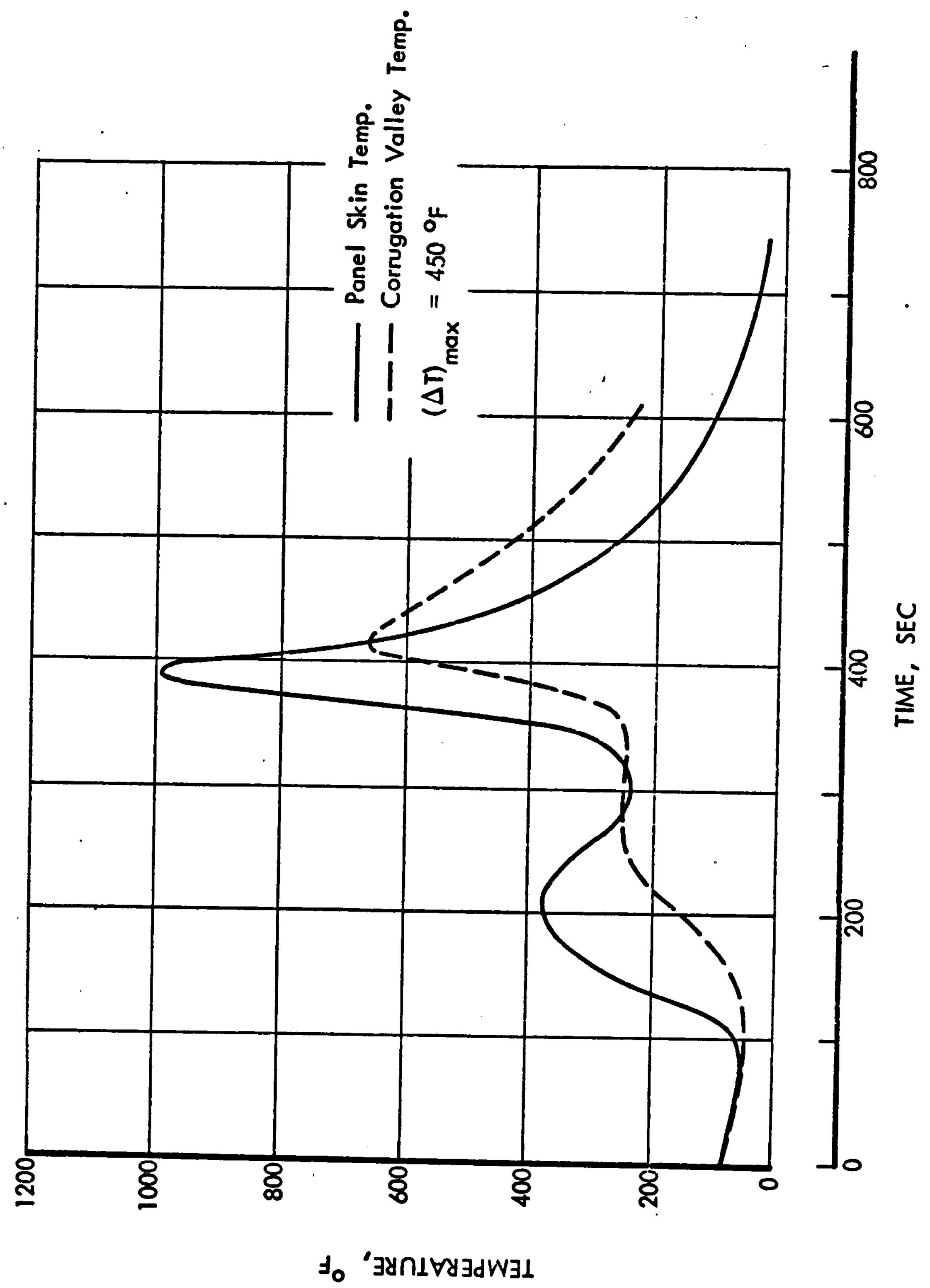


Figure 5-4: FLIGHT ENVIRONMENT - PANEL TEMPERATURES

RUN	P_t (Psi)	T_t (°R)	α (Degrees)	Δt Convective Heat (Sec.)	t_{Event} (8) (Sec.)	REMARKS
1	1000	2500	0	15	365	Preliminary
2			0	25	375	Run
3			0	40	390	
4			1.0			
5			2.0			
6			2.5			Nominal
7						Run
8						
9						
10						

Figure 5-5: PROPOSED TEST RUN SEQUENCE

5.2 Sonic Fatigue Test

The recommended test environment is shown in Figure 5-6. Included are the design overall sound level and panel skin temperature variations with test time. The skin temperature is the maximum measured on the surface between corrugations. It is recommended that this temperature profile be used in order to assure that the correct thermal gradients exist in the panels throughout the test. The overall sound level during reentry does not exceed 120 db for the design trajectory. The resulting acoustic pressure is less than 1% of that occurring during liftoff, and consequently has been neglected.

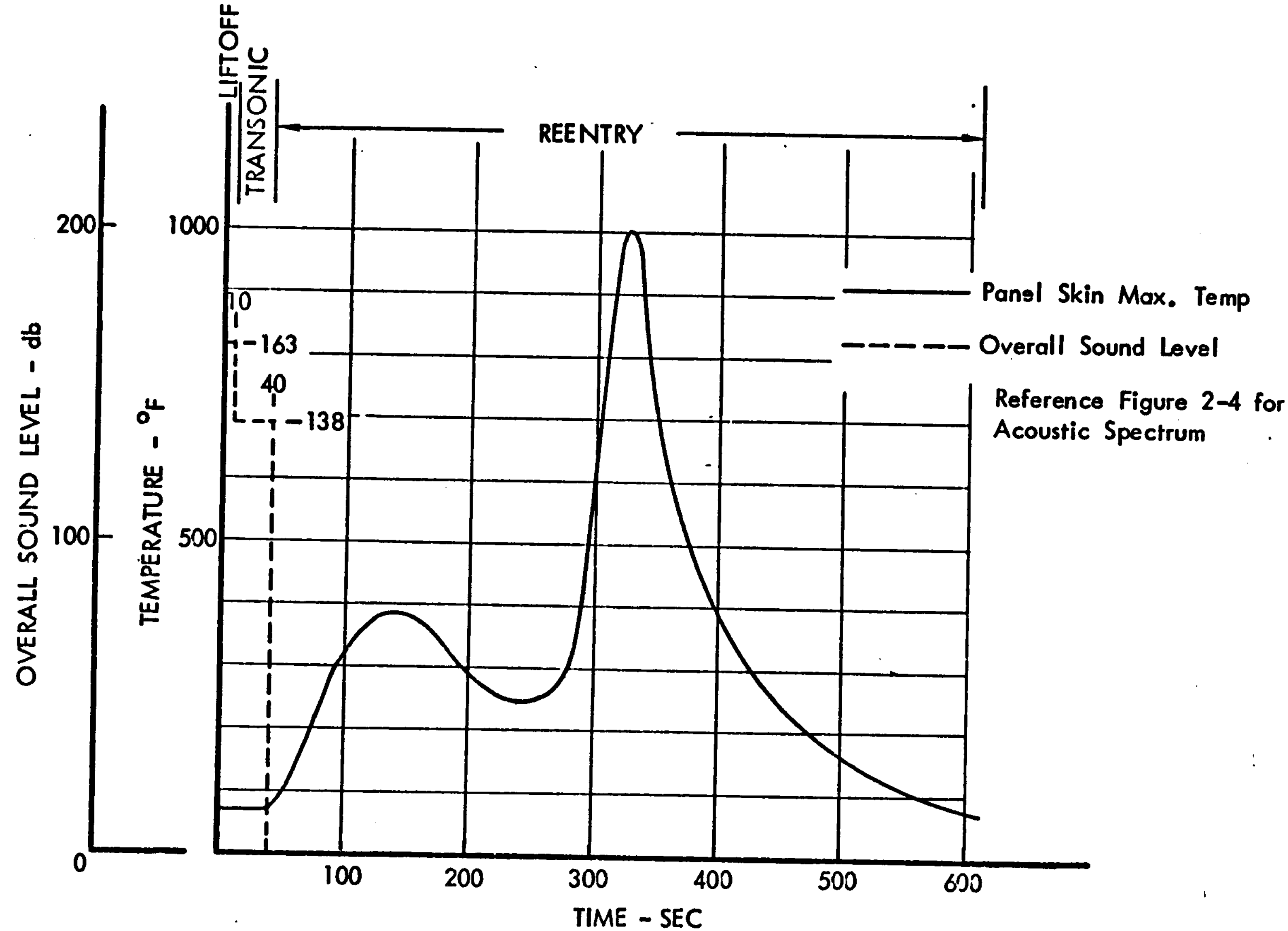


Figure 5-6: PROPOSED TEST ENVIRONMENT - SONIC FATIGUE TEST

6.0 ASSEMBLY INSTRUCTIONS

6.1 Wind Tunnel Assembly Installation Instructions

1) Unbolt test article assembly (SK2-5085-107-1) from shipping container.

2) Place assembly into wind tunnel panel holder cavity. Shim between removable steel channels and the assembly (ZEE Stiffeners) until outboard surface of T.P.S. enclosure (SK2-5085-106-12) is flush with cavity surface ($^{+.00}_{-.04}$). See Figure 6-1.

3) Align assembly with respect to cavity walls such that approximately the same gap exists fore and aft as well as splitting the gap between the sides. Shim between the assembly edge angles and the cavity walls to a gap of $^{.03}_{.00}$ at each hole location shown in Figures 6-2 and 6-3.

4) Check to insure assembly is flush with cavity surface. Transfer hole locations as indicated in Figures 6-2 and 6-3 from cavity to edge angles of support structure (SK2-5085-105-8) and shims.

5) Remove assembly from the cavity and drill .500 - .521 dia. holes in edge members of support structure and in shims.

6) Reinstall assembly and shims into the cavity. Bolt assembly into the cavity.

* 7) Remove lead wire clamps attached to support structure. (See Figure 6-1). Using white nylon gloves, remove T.P.S. panels by first removing plastic protective cover and all assembly outer edge members. (SK2-5085-107-5, -6, -7, -8, -9, -10, -11, -47). The individual panel edge members (180-10194-5, -6, -7, -8) and seals (SK2-5085-107-12, -13) may now be removed. Note that all edge members are serialized on the bottom side. (See Figure 6-1 for sequence). (Note that panel edge member 5-2 is penetrated by thermocouples T_{25} and T_{38} (See Fig. 4-1) and must not be removed from the TPS panel.)

* Indicates an operation requiring clean white gloves and special precaution to not contaminate or damage T.P.S. panels.

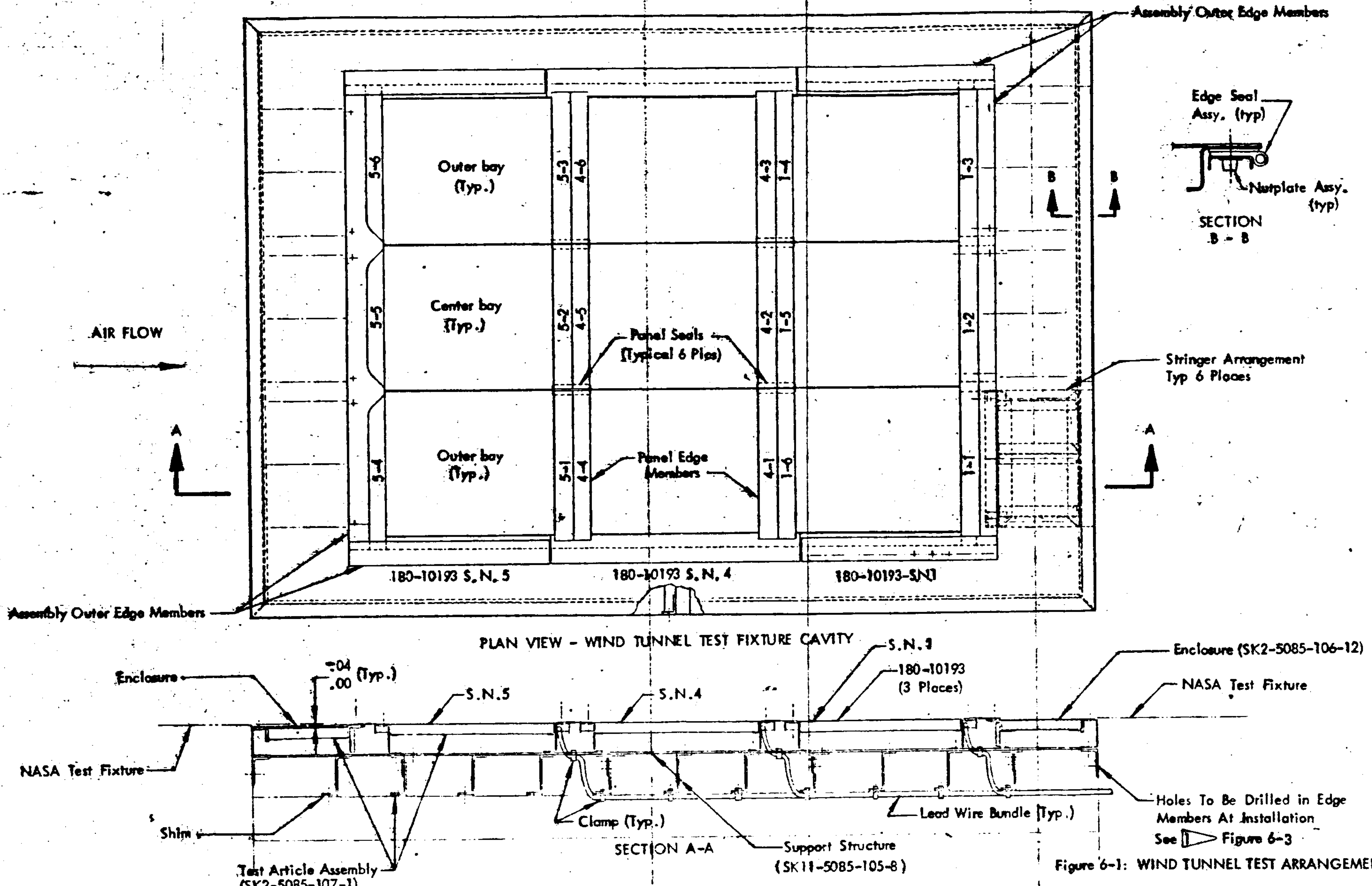


Figure 6-1: WIND TUNNEL TEST ARRANGEMENT

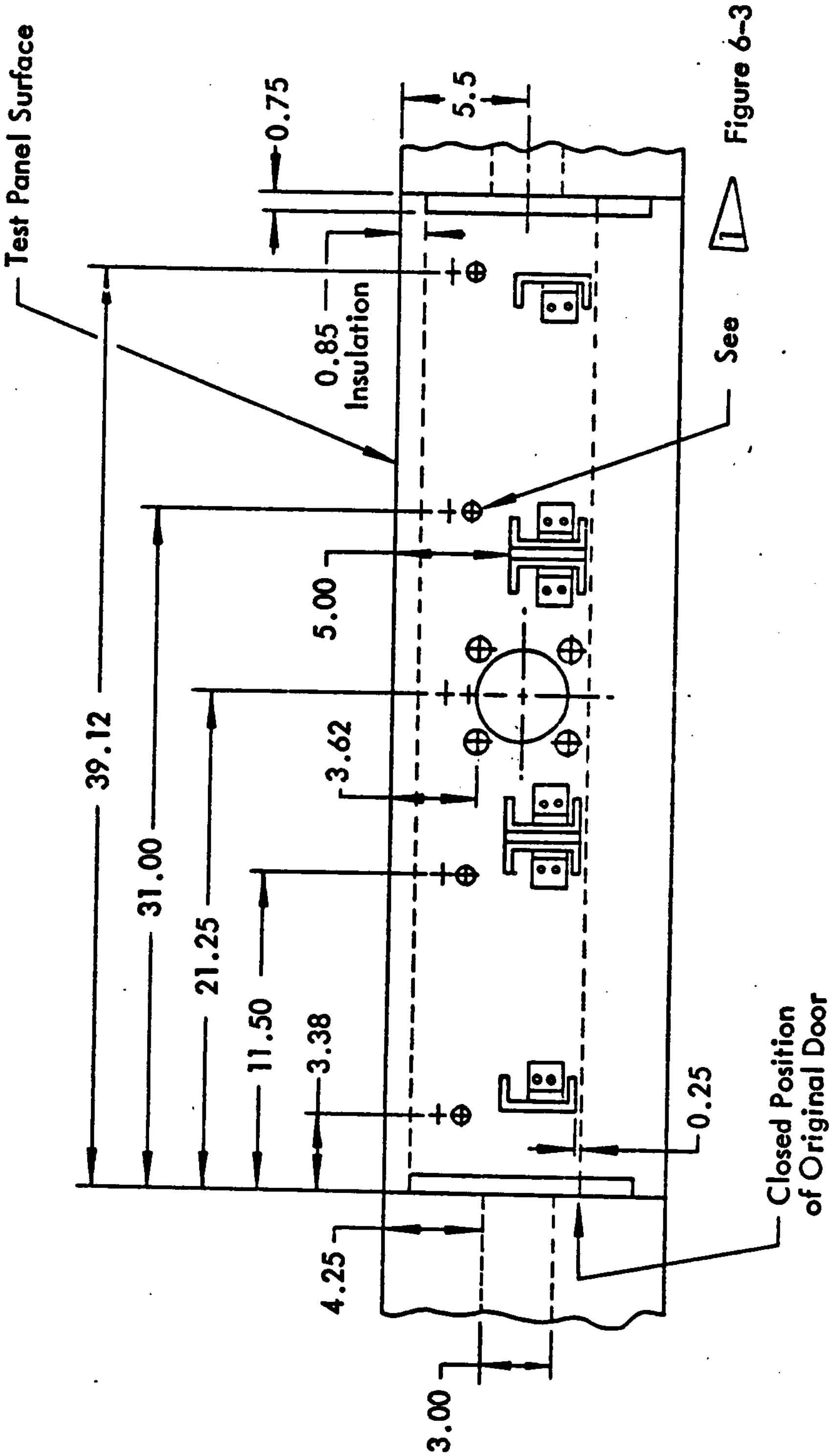
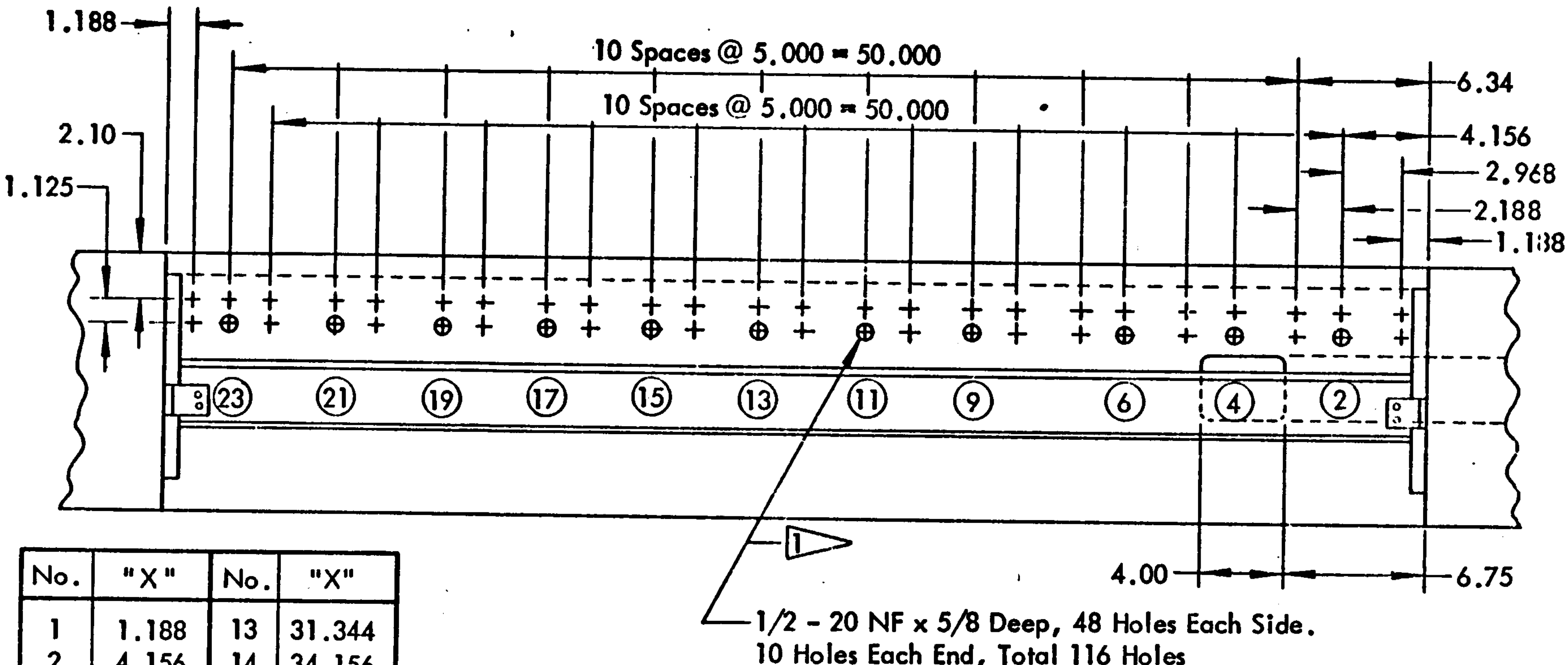


Figure 6-2: WIND TUNNEL PANEL HOLDER, SECTION A-A



No.	"X"	No.	"X"
1	1.188	13	31.344
2	4.156	14	34.156
3	6.344	15	36.344
4	9.156	16	39.156
5	11.344	17	41.344
6	14.156	18	44.156
7	16.344	19	46.344
8	19.156	20	49.156
9	21.344	21	51.344
10	24.156	22	54.156
11	26.344	23	56.344
12	29.156	24	59.156

1 Edge Angles Drilled to Match Holes Shown by ⊕. (11) Each Side, (4) Each End
Install NAS 1308, or NAS1108 Bolts
Typical 30 Places. Shim as Required to Provide Gap of $^{.03}_{.00}$ in.

Figure 6-3: WIND TUNNEL PANEL HOLDER, SECTION B-B

*8) Starting with the leading edge T.P.S. panel (S.N. 4), carefully lift at the leading edge of the outer bays until the panel can be grasped by the edge closure "ZEE" member. Check to insure an adequate amount of instrumentation wiring is available to allow panel to be removed and placed along side the test cavity. Carefully remove the panel while feeding instrumentation wire thru hole in support structure. Note: Use care to minimize deflection in omega joints between bays. Set panel aside for re-assembly. Remove the remaining two TPS panels in a similar manner.

Note: In the following seal installation apply only sufficient pressure to bring it into contact with cavity wall.

9) Loosen all edge seal assemblies (See Figure 6-1) by backing off fasteners. Fit the four corner assemblies (SK2-5085-107-17, -18) into position against the cavity wall using seal tool**. Tighten the nutplate assemblies (-19 and -20). See 17 of SK2-5085-107. Coat faying surfaces of corner seals with adhesive** per 11 and install -36, -37 and -39 seal assemblies by butting them against the corner seal assemblies and then sliding each into contact with the cavity walls. Secure the nutplates assemblies (-22, -24, and -29) per 17. The seal shall now be completed by measuring the four gaps remaining and trimming the -38 seal assemblies** per 19. Coat the faying surfaces of the -36, -37, and -39 assemblies per 11, and slide the -38 assemblies into position. Secure the -27 nutplate assemblies per 17.

Note: Minimum cure time for 11 adhesive is 24 hours.

----

* Indicates an operation requiring clean white gloves and special precaution to not contaminate or damage T.P.S. panels.

** Bagged with assembly.

*10) Install T.P.S. panels by carefully placing each on the stand-offs using the reverse of the procedure as defined in step #8. Install panel edge member by lightly coating screws with EZ-Off 990** and finger tighten only. Replace assembly outer edge members, lubricating the screws with EZ-Off 990. Tighten all edge member fasteners per 16. Clean panels of any excess EZ-Off 990 or other contamination by carefully wiping with cheese cloth impregnated with a suitable solvent, such as Methyl-Ethyl-Ketone, using approved cleaning procedures for thin-gauge titanium metal structures. Caution: Do not use chlorinated solvents.

11) Replace plastic protective cover and remove only when ready for testing.

12) Route and clamp instrumentation lead wires as shown in Figure 6-1. Connect instrumentation lead wires to facility service.

* Indicates an operation requiring clean white gloves and special precaution to not contaminate or damage T.P.S. panels.

** Bagged with assembly.

6.2 Sonic Assembly Installation Instructions

1) Unbolt test article assembly (SK2-5085-107-2) from shipping container.
2) Place assembly into NASA furnished facility support structure. Install remaining frame members, adjusting the assembly so that the outboard face is nominally .10 $\pm$ .03 below flush with the NASA support structure. See Figure 6-4.
3) Place shims around the perimeter of the assembly such that a gap of no greater than .030 in. exists at each hole location in assembly edge members (SK11-5085-105-4 & -14). Clamp assembly to the support structure.
4) Tranfer hole locations from edge members (-14) and (-4's) to the facility support structure.
5) Remove assembly from the test support structure and drill .375 - .391 diameter holes into the facility support structure and shims.
6) Reinstall T.P.S. assembly and shims into the facility support structure. Bolt the assembly to support structure using bolts shown in Figure 6-4.
7) Install assembly outer edge seal by drilling $\begin{matrix}.291\\.279\end{matrix}$ dia. holes in facility and details, and bolting in place as shown in Figure 6-4.
8) Route and clamp all instrumentation leads and accelerometer cooling lines as shown in Figure 6-4. Connect all leads and cooling lines to facility service.
9) Remove plastic protective cover from T.P.S. panels just prior to testing to prevent contamination.

NOTE: If necessary to handle T.P.S. panels (180-10193) use only clean white nylon gloves to prevent contamination. All contamination (finger prints, debris, etc.) must be thoroughly removed prior to test using a suitable solvent, such as Methyl Ethyl Ketone, and approved cleaning procedures for thin-gauge titanium metal structures. (Caution: Do not use chlorinated solvents).

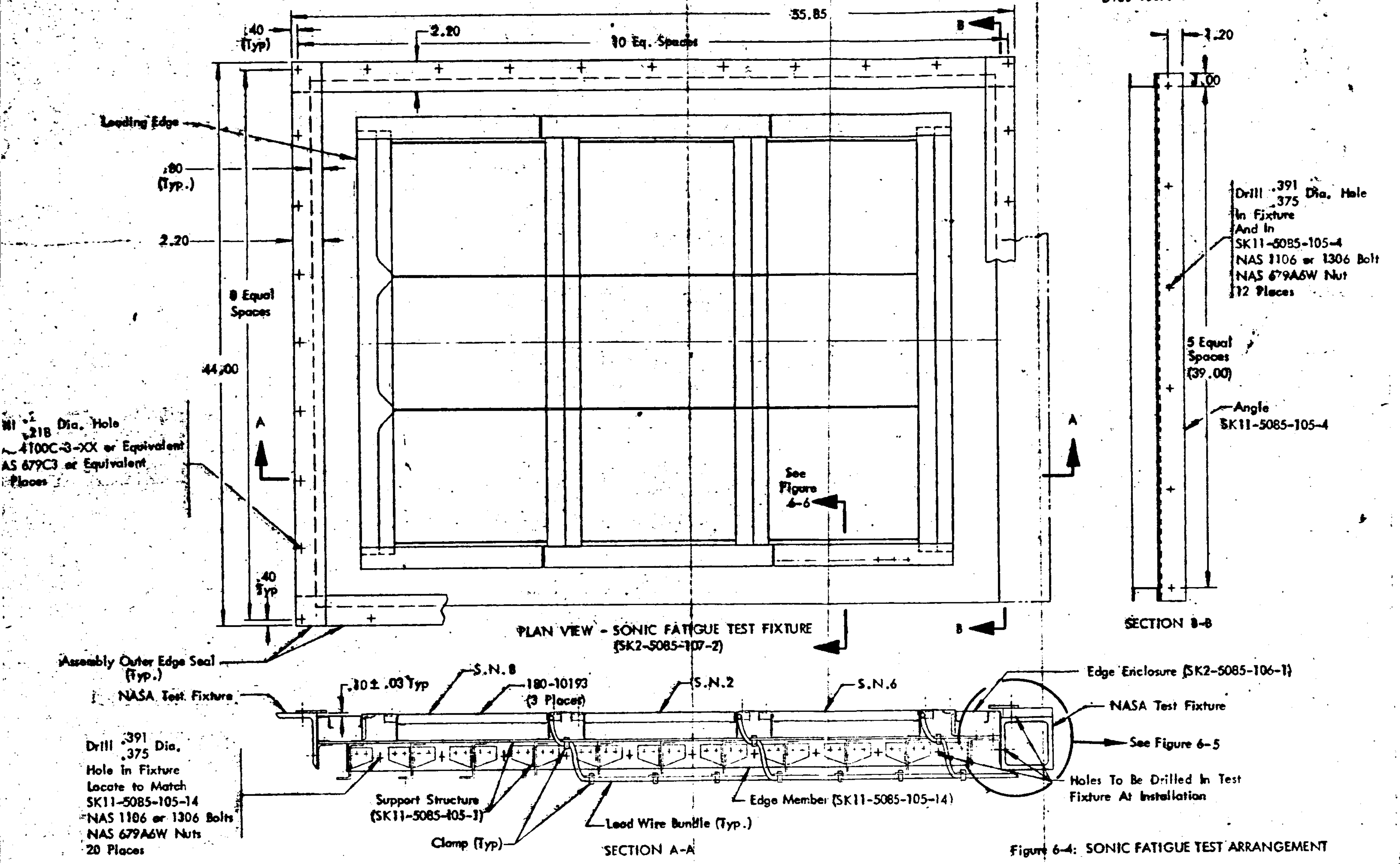


Figure 6-4: SONIC FATIGUE TEST ARRANGEMENT

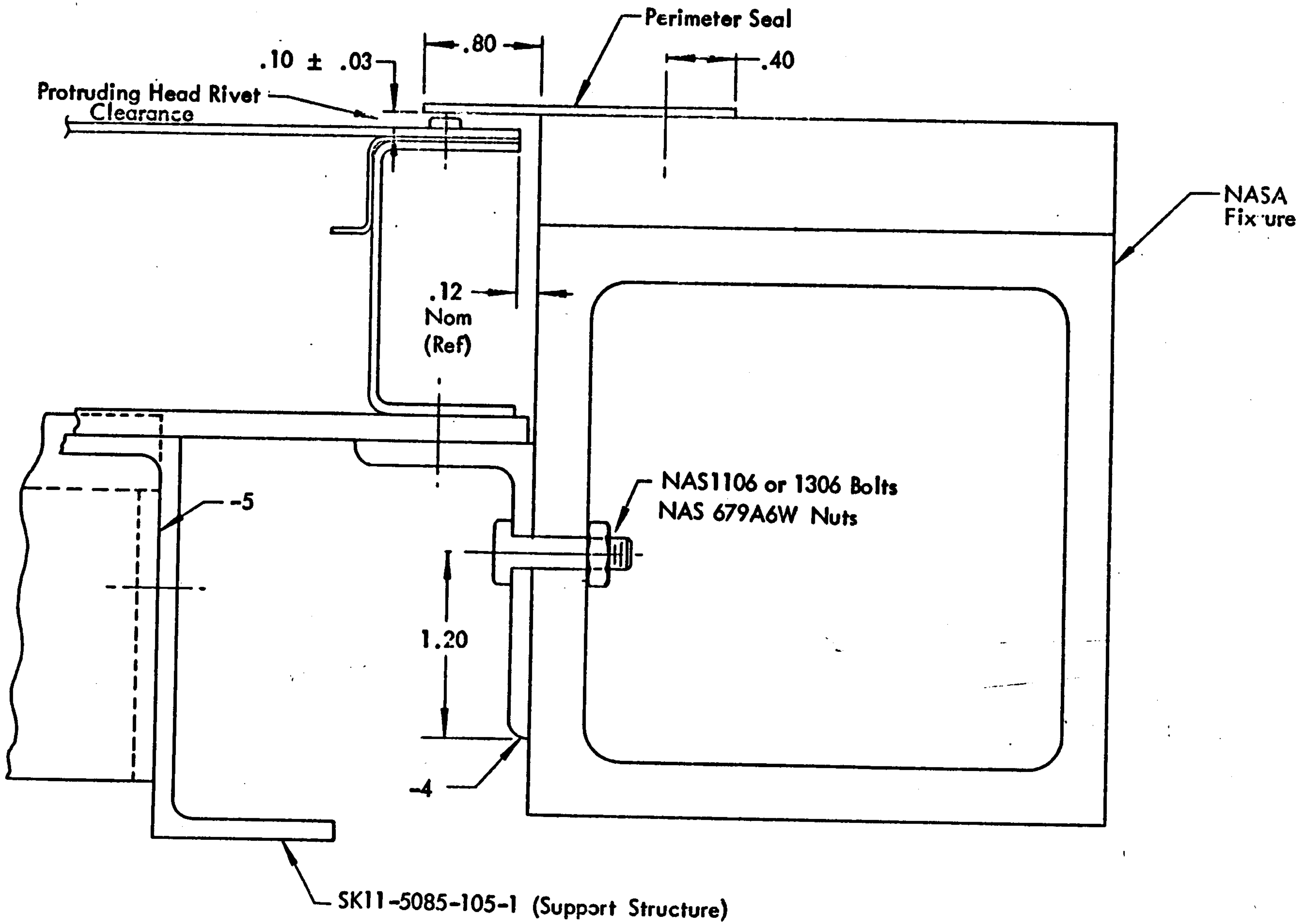


Figure 6-5: VIEW - SONIC FATIGUE TEST ARRANGEMENT

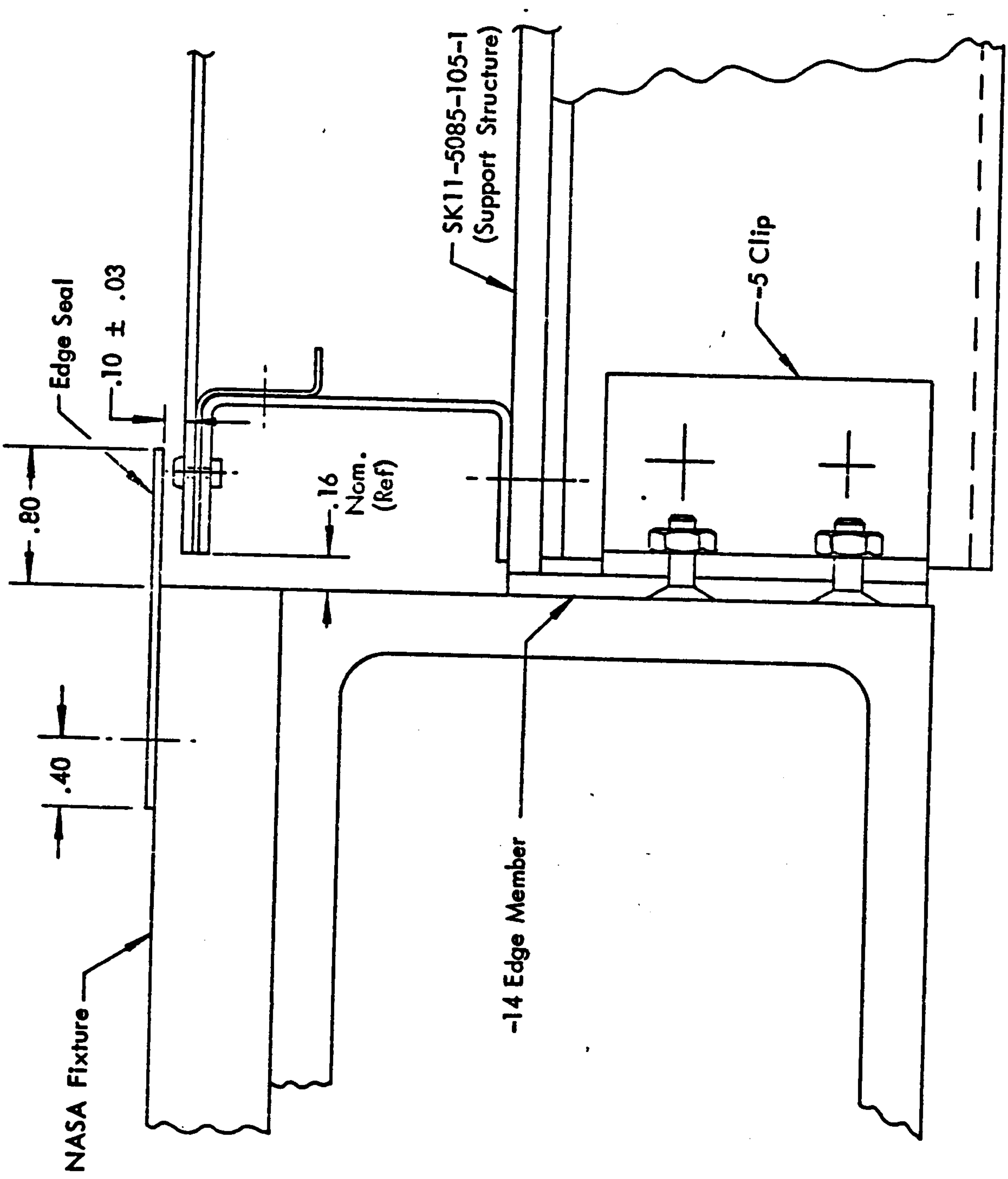
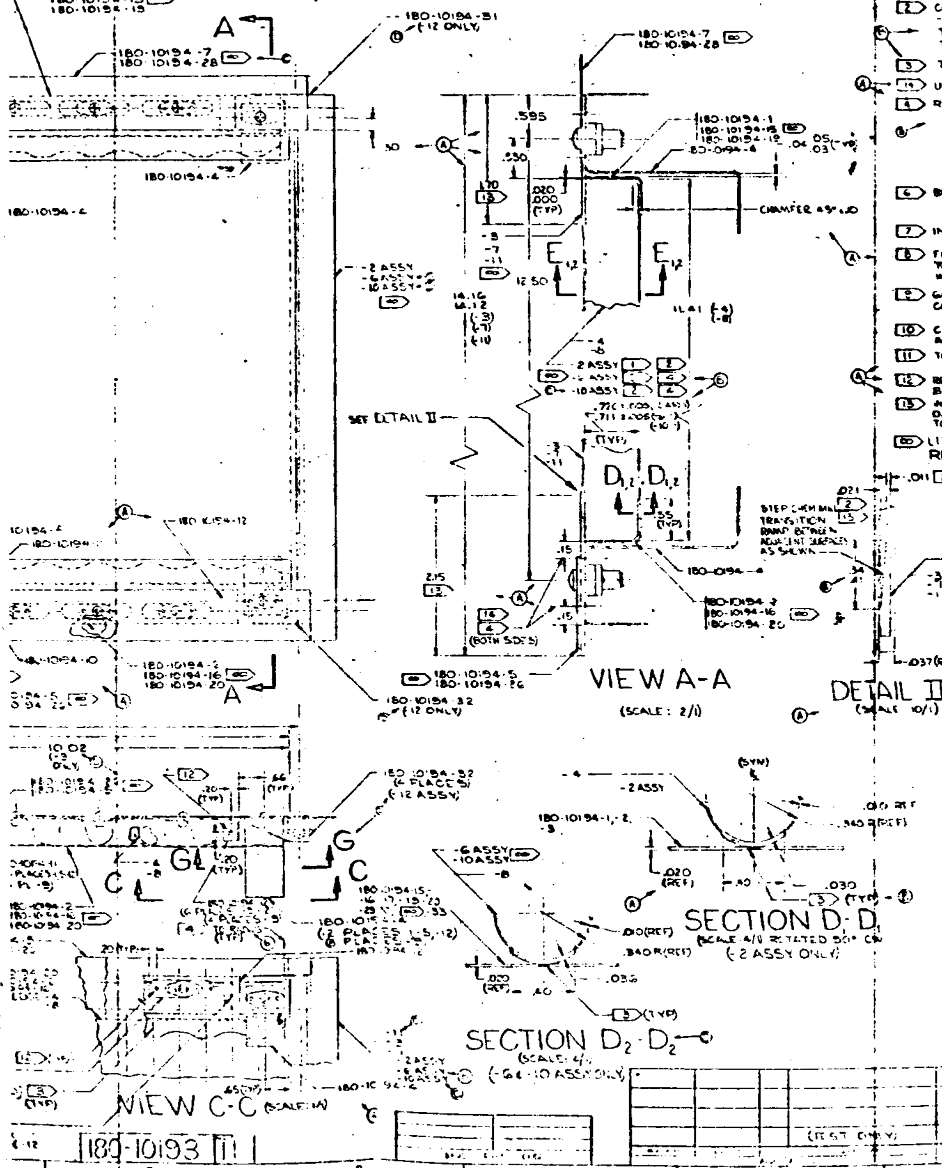


Figure 6-6: SECTION - SONIC FATIGUE TEST ARRANGEMENT

7.0 DRAWINGS



11. -8 ONLY, BACK INSIDE THIS RADIUS ... CHEM MILL
10. FORM ... PRIOR TO CHEM MILLING; ... -7 & -11 AFTER CHEM MILLING
1. DIFFUSION WELD, SKINS -5 & CORRUGATION (-4, ...ING - 2 ASSY), AT 1775°F ± 20°F FOR 3 HRS. 60 PSI MINIMUM PRESSURE.
2. CHEM MILL PER BAC 5842 - REMOVE .005 PER SIDE OF ITEMS -3 & -4 PRIOR TO DIFFUSION WELDING THEN CHEM MILL -2 ASSY TO THICKNESSES INDICATED. CHEM MILL -7 & -8 TO INDICATED THICKNESSES PRIOR TO ASSY BY RESISTANCE SEAM WELDING. CHEM MILL TOL ±.005
3. TIG WELD PER BAC 5967, CLASS A
14. ULTRASONIC INSPECT ... WELD PER ENGINEERING INSTRUCTIONS.
4. RESISTANCE SEAM WELD PER BAC 5925 CLASS A
NOTE: WELD GEOMETRY REQUIREMENTS TO BE ESTABLISHED BY ENGINEERING.
6. BEFORE INSTALLATION LUBRICATE MACH SCREWS WITH EZ-OFF 990.
7. INSTALLATION TORQUE 8-12 INCH-LBS
8. FITUP & DRILL FOR MACHINE SCREWS AFTER ... PARTS, 180-10194-1, 2, 3, 15, 16, 17, 19, 20, 33) TO THE ASSEMBLY. DRILLING METHOD MUST INSURE THAT THERE ARE NO BURRS, INCLUSIONS NOR COOLANT CONTAMINATION BETWEEN ... MEMBERS AND FACE SKIN AFTER DRILLING.
9. 6AL-2SN-4ZR-2MO TITANIUM SHEET PER MIL-T-9046F, TYPE III, COMP G, DUPLEX ANNEALED
10. CLEAN PER BAC 5753 AFTER 1
11. THREE (3) SPOTS MINIMUM.
12. RESISTANCE SPOTWELD PER BAC 5925, CLASS A
13. INCREASED SKIN THICKNESS, OUTSIDE SURFACE ONLY TO DIMENSIONS SHOWN
LIMITED - SEE L/M FOR RELEASE

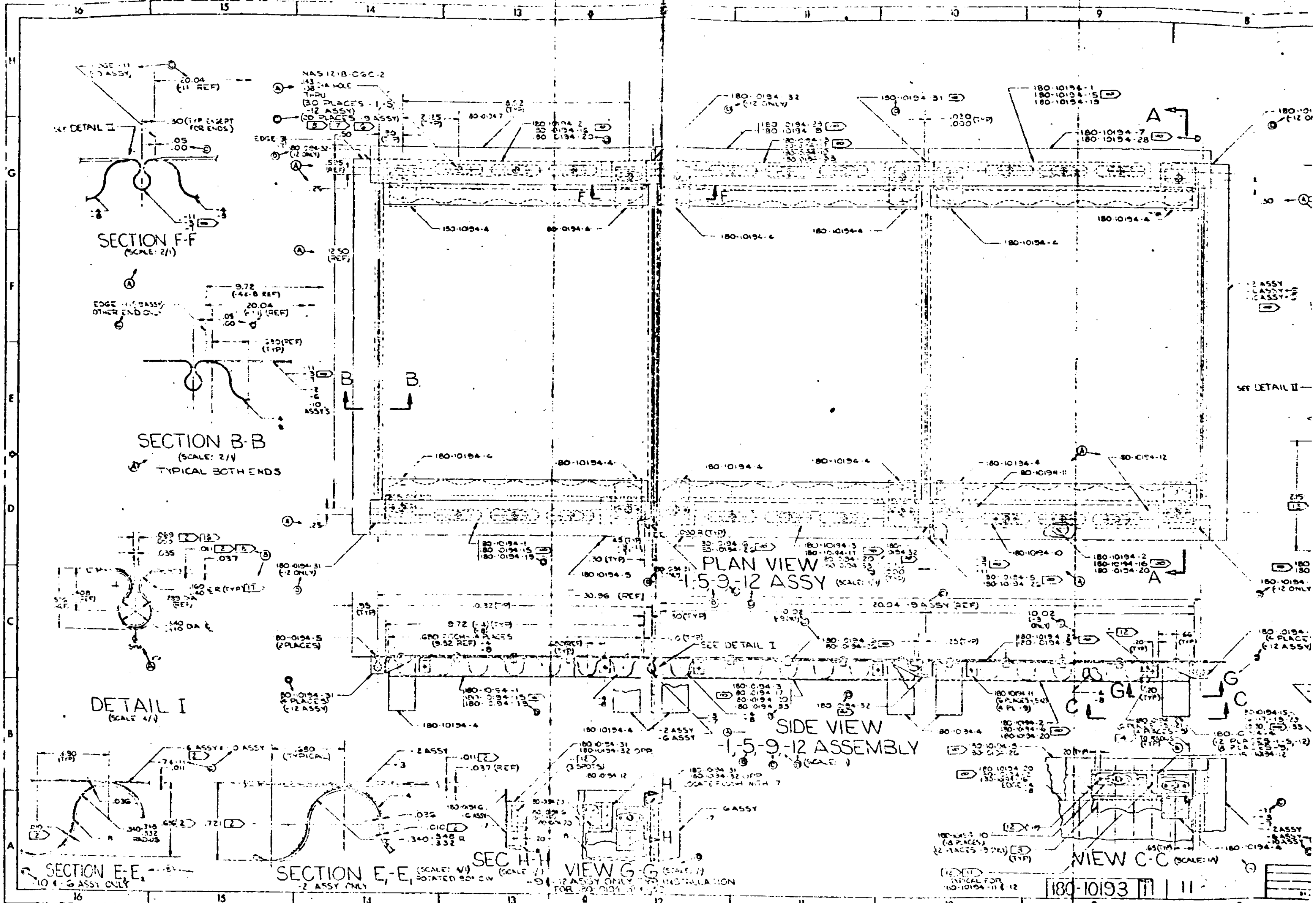
			Qty	Part No.	Description	Notes	Zone
✓			2	180-10194-32	OPP 180-10194-31		D
✓			4	180-10194-31	TAB		D
✓			2	180-10194-28	STRIP, CLOSING		C
✓			2	180-10194-26	STRIP, COVER		C
✓			2	180-10194-20	STIFFENER, EDGE		C
✓			2	180-10194-19	STIFFENER, EDGE		C
-10			1	-11	SKIN	9 2	C
✓			1	-10	SKIN ASSY	4 14	C
-	-		-	-9	PANEL ASSY, ... RESISTANCE SEAM WELD		D
			2	180-10194-33	STIFFENER, EDGE		D
	✓		2	180-10194-17	STIFFENER, EDGE		C
	✓		2	180-10194-16			C
	✓		2	180-10194-15	STIFFENER, EDGE		C
				-8	CORRUGATION	9 1	C
				-7	SKIN	9 2	C
	✓		1	-6	SKIN ASSY	4 14	C
	-		-	-5	PANEL ASSY, ...		C
				NAS 1218-06-2	SCREW, MACHINE	6 7 8	C
				180-10194-12	OPP 180-10194-11		C
				180-10194-11	CLIP		C
				180-10194-10	STRUT ASSY		C
	✓	✓	1	180-10194-8	STRIP, CLOSING		C
	✓	✓	2	180-10194-7	STRIP, CLOSING		C
	✓			180-10194-6	STRIP COVER		C
	✓		2	180-10194-5	STRIP COVER		C
				180-10194-4	CLIP ASSY		C
			2	180-10194-3	STIFFENER, EDGE		C
		✓	2	180-10194-2			C
			2	180-10194-1	STIFFENER, EDGE		C
-	-	-		-12	PANEL ASSY, ... RESISTANCE ...		C
				-4	CORRUGATION	9 1	C
				-3	SKIN	9 2	C
				-2	SKIN ASSY	1 ... 14	C
				-1	PANEL ASSY		C

(TEST ONLY)

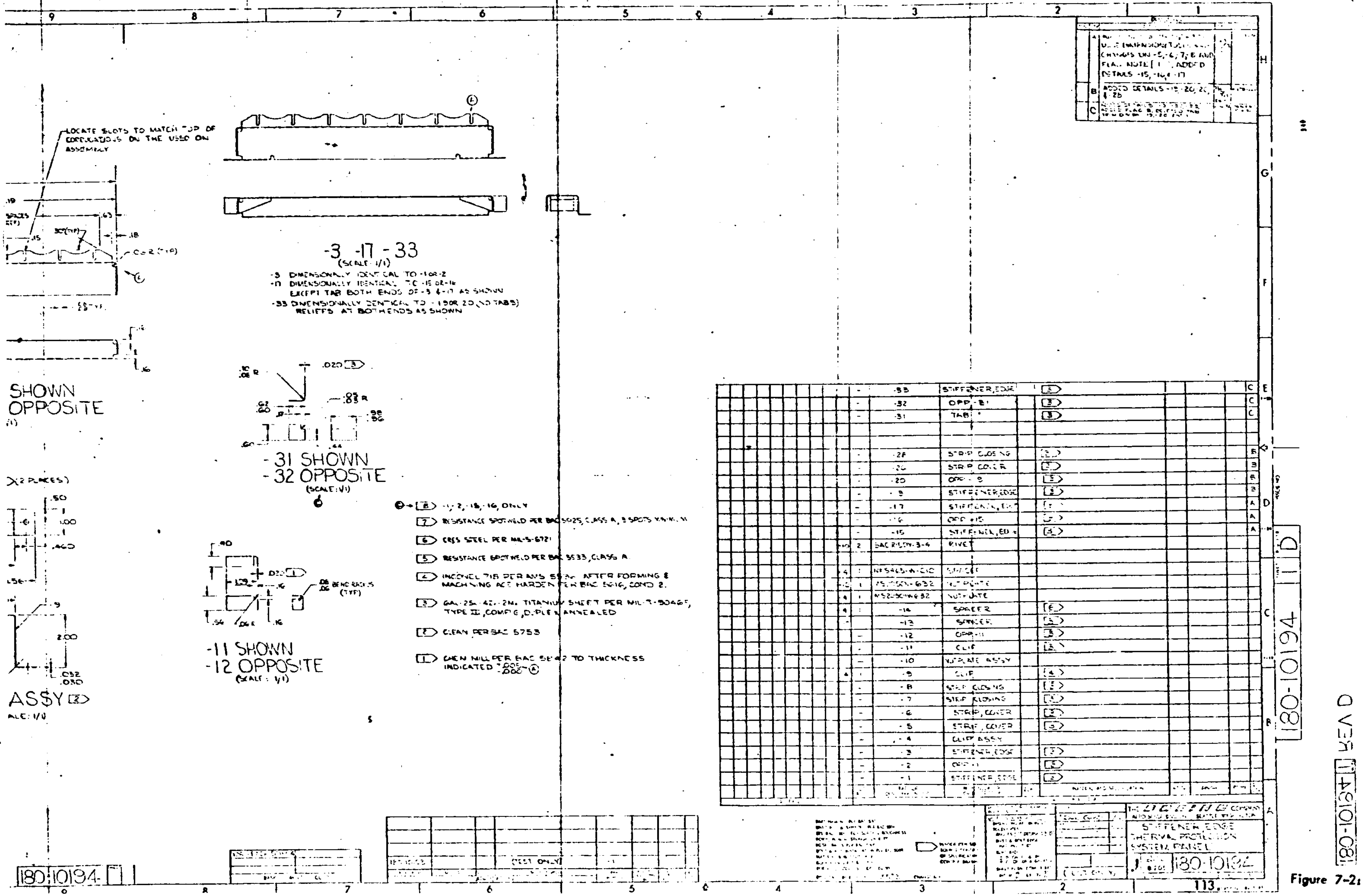
180-10193 II D

Figure 7-1: 180-10193 II REV D

180-10193

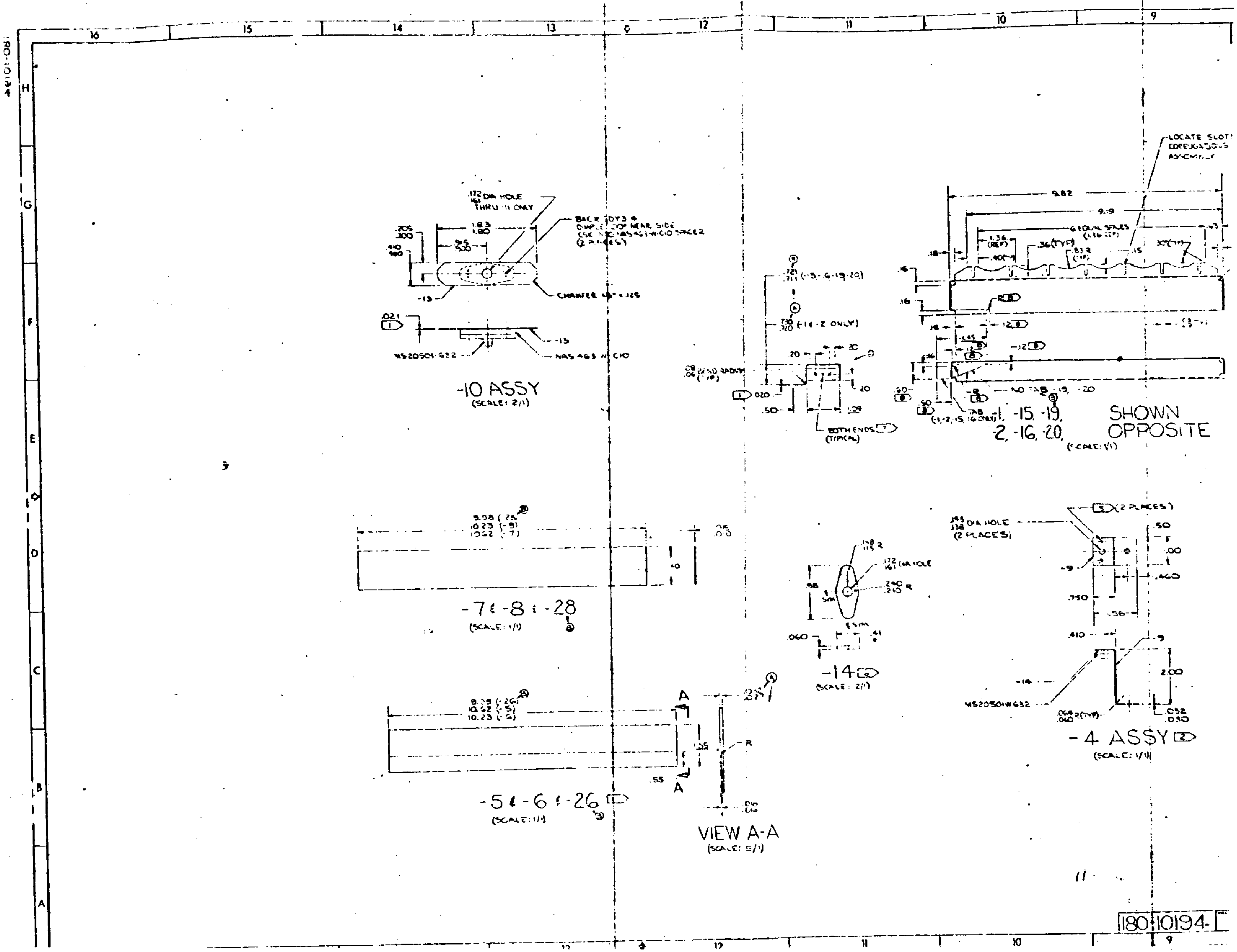


SECTION F-F
(SCALE: 2/1)
SECTION B-B
(SCALE: 2/1)
TYPICAL BOTH ENDS
DETAIL I
(SCALE 4/1)
SECTION E-E
2 ASSY ONLY
SECTION E-E
ROTATED 90° CW
SEC H-H
VIEW G-G
PLAN VIEW
-1,-5,-9,-12 ASSY
SIDE VIEW
-1,-5,-9,-12 ASSEMBLY
VIEW C-C
SEE DETAIL I
SEE DETAIL II
NAS 1218-C6C-2
180-10193

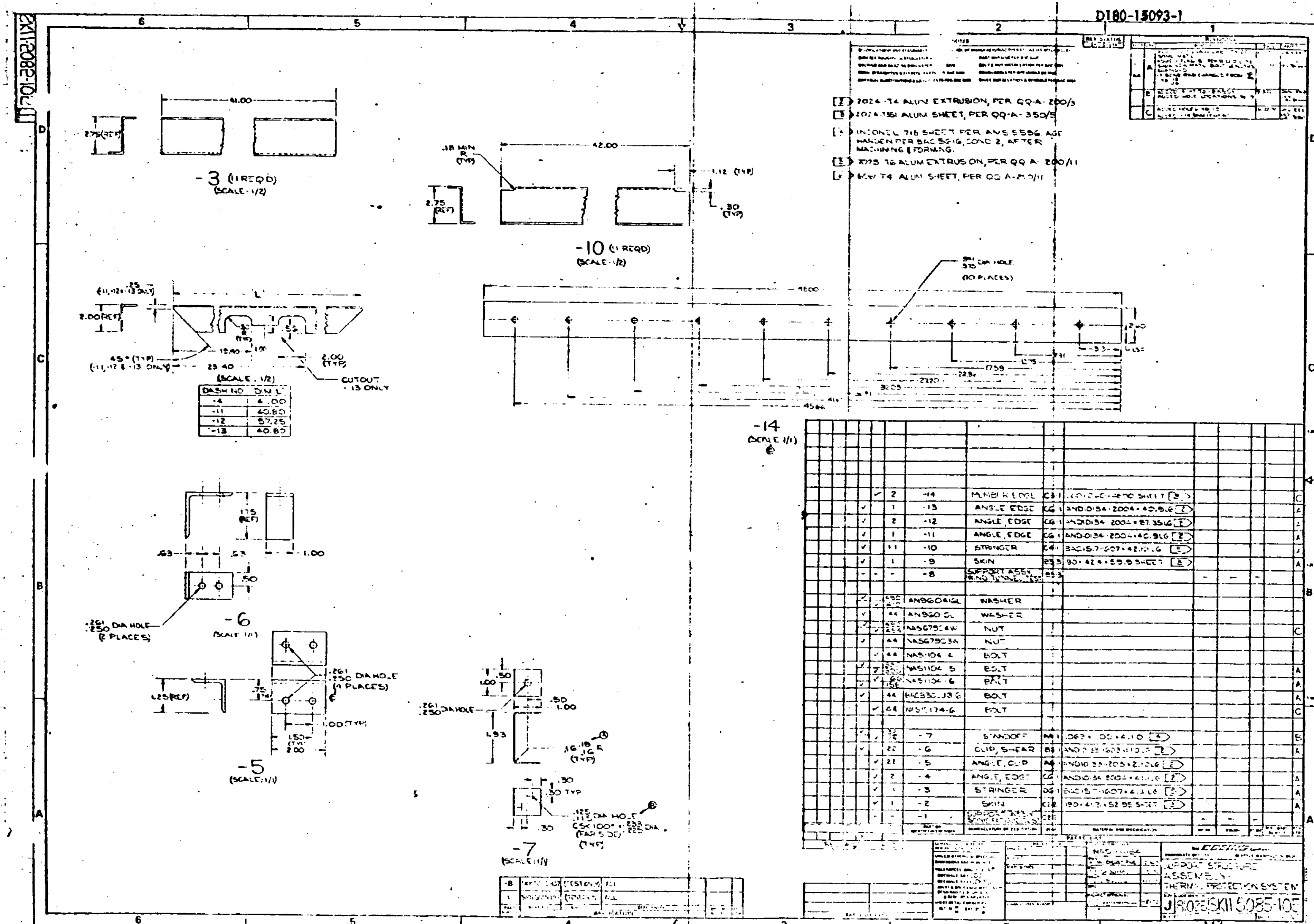


LOCATE SLOTS TO MATCH TOP OF CORRUGATIONS ON THE USED ON ASSEMBLY
-3 -17 -33
(SCALE 1/1)
-31 SHOWN
-32 OPPOSITE
(SCALE 1/1)
-11 SHOWN
-12 OPPOSITE
(SCALE 1/1)
SHOWN
OPPOSITE
(2 PLACES)
ASSY
CRES STEEL PER MIL-S-6721
CLEAN PER BAC 5753
STIFFENER, EDGE
STRIP, COVER
STRIP, CLOSING
CLIP ASSY
SPACER
NUTPLATE
RIVET
STIFFENER, EDGE
THERMAL PROTECTION
SYSTEM PANEL
180-10194
TEST ONLY

Figure 7-2.



-10 ASSY
(SCALE: 2/1)
-7 & -8 & -28
(SCALE: 1/1)
-5 & -6 & -26
(SCALE: 1/1)
VIEW A-A
(SCALE: 5/1)
-14
(SCALE: 2/1)
-1, -15, -19, -2, -16, -20, SHOWN OPPOSITE
(SCALE: 1/1)
-4 ASSY
(SCALE: 1/1)
LOCATE SLOTS
CHAMFER
MS20501-632
NAS 463
MS20501W632
BOTH ENDS
(TYPICAL)
NO TAB
180 10194



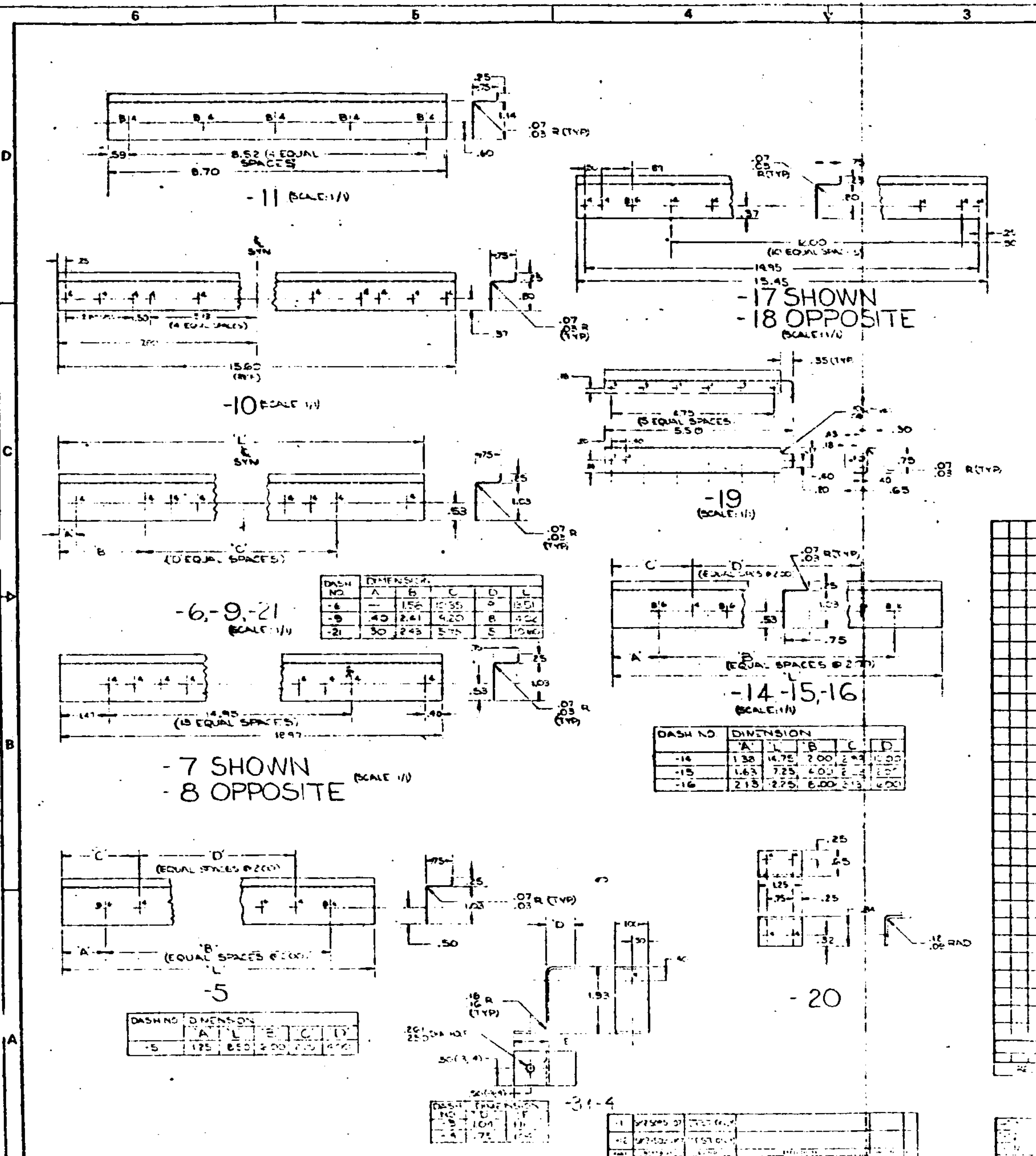
Notes:

1. 2024-T4 ALUM EXTRUSION, PER QQ-A-200/3
2. 2024-T351 ALUM SHEET, PER QQ-A-250/5
3. INCONEL 718 SHEET PER AMS 5596 AGE HARDEN PER BAC 5616, COND 2, AFTER MACHINING & FORMING.
4. 7075-T6 ALUM EXTRUSION, PER QQ-A-200/11
5. 6061-T4 ALUM SHEET, PER QQ-A-250/11

PARTS LIST

QTY	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	REV
2	-14	MEMBER EDGE	C3	.40 × 2.40 × 46.00 SHEET 3	C
1	-13	ANGLE EDGE	C6	AND10134-2004 × 40.8 LG 2	A
2	-12	ANGLE, EDGE	C6	AND10134-2004 × 57.35 LG 2	A
1	-11	ANGLE, EDGE	C6	AND10134-2004 × 40.8 LG 2	A
11	-10	STRINGER	C4	BAC1517-607 × 42.00 LG 5	A
1	-9	SKIN	B3	.90 × 42.4 × 59.5 SHEET 3	A
-	-8	SUPPORT ASSY WIND TUNNEL TEST	B3		
[illegible]	AN960416L	WASHER			
44	AN960-6L	WASHER			
[illegible]	NAS679C4W	NUT			C
44	NAS679C3W	NUT			
44	NAS1104-4	BOLT			
[illegible]	NAS1104-5	BOLT			A
[illegible]	NAS1104-6	BOLT			A
44	BACB30LJ3-6	BOLT			A
44	NAS1174-6	BOLT			C
[illegible]	-7	STANDOFF	A4	.063 × 1.00 × 4.10 4	B
22	-6	CLIP, SHEAR	B5	AND10133-1603 × 1.10 LG 2	A
22	-5	ANGLE, CLIP	A5	AND10133-2005 × 2.10 LG 2	
2	-4	ANGLE, EDGE	C6	AND10134-2004 × 4.00 LG 2	A
1	-3	STRINGER	D6	BAC1517-1607 × 41.00 LG 5	A
1	-2	SKIN	C12	.190 × 41.3 × 52.95 SHEET 3	A
-	-1	SUPPORT ASSY SONIC FATIGUE TEST	C12		

Figure 7-3:



NOTES

3. 718 INCONEL SHEET, PER AMS 5596, (1750°F ANNEALED) AGE HARDEN PER BAC 5616 COND 2 AFTER MACHINING & FORMING

5. 600 INCONEL SHEET, PER MIL-N-6840

4. REMOVE BURRS & BREAK SHARP EDGES .005 MAX

7. SEE PLAN VIEW -12 ASSY FOR ORIENTATION OF -19 & -22

-22

		Qty	Part No.	Nomenclature	Code	Material / Description
✓	✓	120	NS2050-032	NUTPLATE		
✓	✓	4	NS2052-06	NUTPLATE		
✓		16	-22	CLIP		.025 × .50 × 2.0 [3]
	✓	2	-21	STIFFENER	C6	.025 × 2.2 × 10.70 [3]
	✓	4	-20	CLIP	A4	.063 × 1.3 × 1.9 [5]
✓		16	-19	STIFFENER	C4	.025 × .5 × 6.5 [5]
✓	✓	2	-18	OPP -17		
✓	✓	2	-17	STIFFENER	D4	.025 × 1.85 × 15.7 [3]
✓		6	-16		B4	.025 × 2.2 × 3.8 [3]
✓		4	-15		B4	.025 × 2.2 × 7.5 [3]
✓		4	-14	STIFFENER	B4	.025 × 2.2 × 14.8 [3]
✓		1	-13	SKIN	C3	.063 × 42.55 × 60.00 [5]
-		-	-12	ENCLOSURE ASSEMBLY		
✓	✓	6	-11	STIFFENER	D6	.025 × 2.2 × 8.82 [3]
✓	✓	2	-10	STIFFENER	C6	.025 × 1.85 × 15.7 [3]
	✓	2	-9	STIFFENER	C6	.025 × 2.2 × 14.0 [3]
	✓	2	-8	OPP -7	B6	
	✓	2	-7	STIFFENER	B6	.025 × 2.2 × 15.1 [3]
	✓	4	-6	STIFFENER	A6	.025 × 2.2 × 8.9 [3]
✓		2	-5	STIFFENER	A5	.025 × 2.2 × 13.6 [3]
✓	✓	12	-4	CLIP	A5	.063 × 1.1 × 3.8 [3]
✓	✓	12	-3	CLIP	A5	.063 × 1.1 × 3.9 [3]
	✓	1	-2	SKIN	C2	.063 × 42.00 × 53.00 [5]
-		-	-1			

PARTS LIST

NAS1-11154

THE BOEING COMPANY

ENCLOSURE ASSEMBLY

THERMAL PROTECTION SYSTEM

J 5025 SK2-5085-106

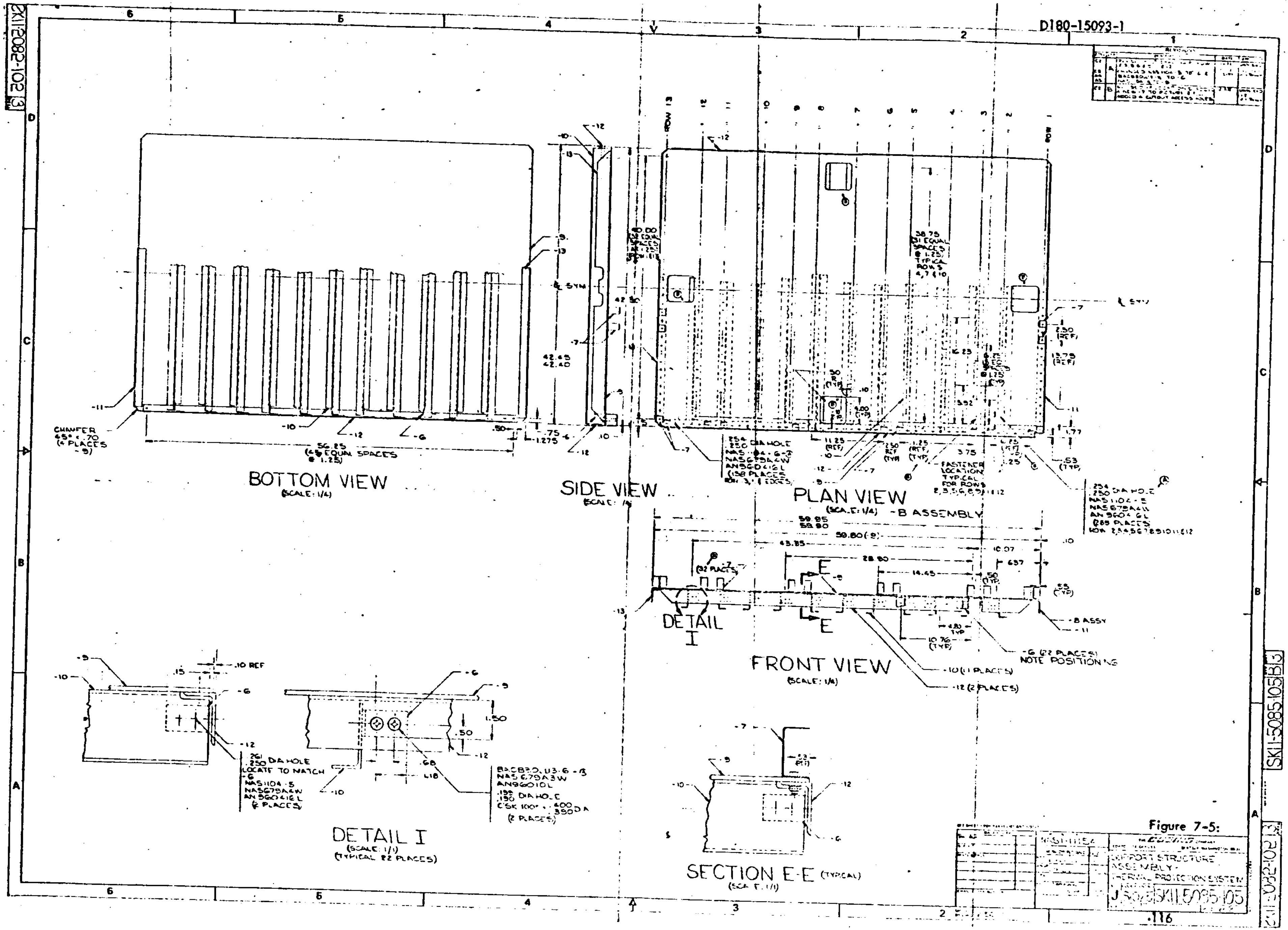
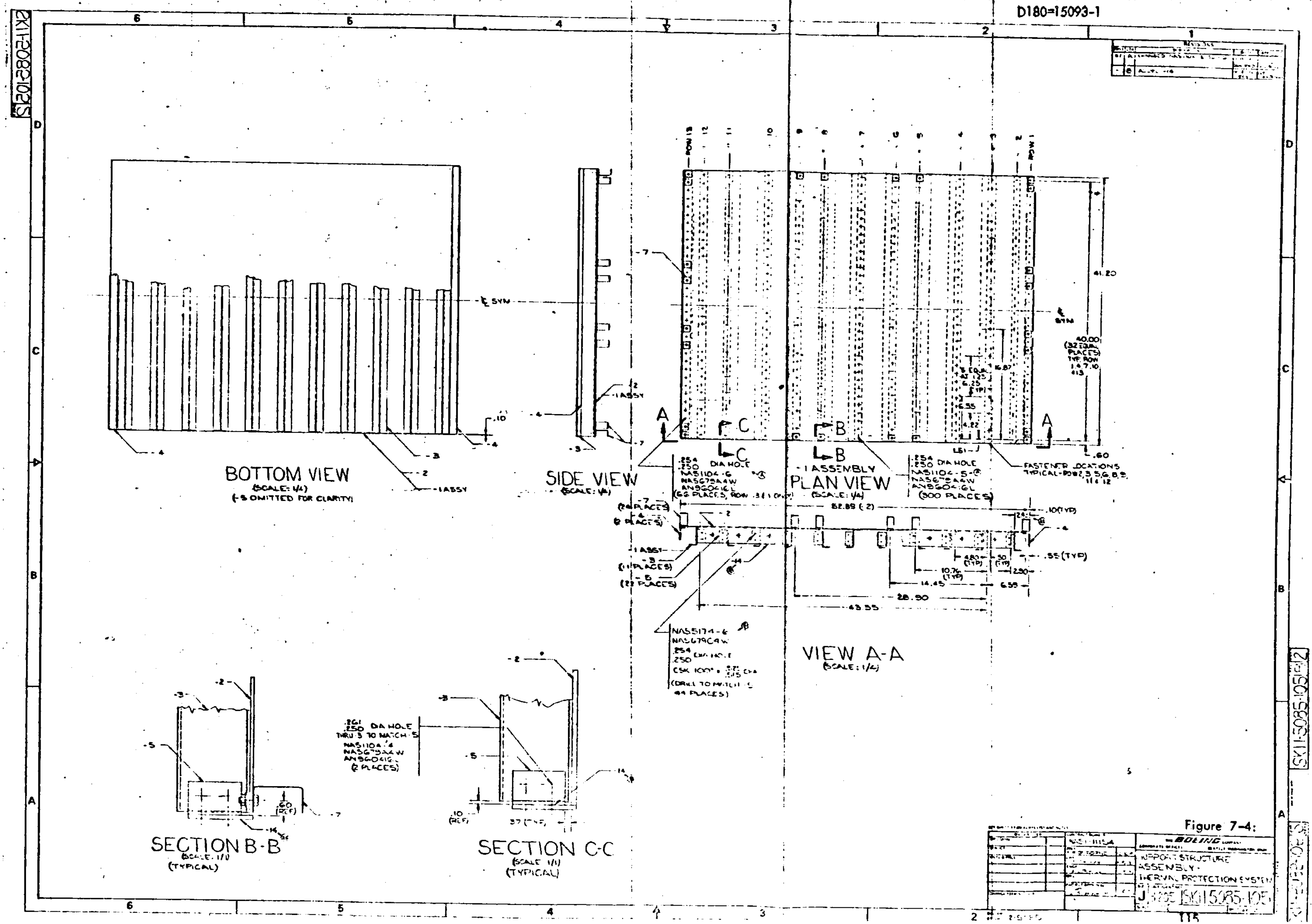

D180-15093-1
SK11-5085-105
BOTTOM VIEW
(SCALE: 1/4)
CHAMFER 45° x .70 (4 PLACES) -9
56.25 (45 EQUAL SPACES @ 1.25)
SIDE VIEW
42.45
42.40
PLAN VIEW
(SCALE: 1/4) -B ASSEMBLY
38.75 (31 EQUAL SPACES @ 1.25) TYPICAL ROWS 4,7 & 10
FASTENER LOCATION TYPICAL FOR ROWS 2,3,5,6,8,9,11,12
ROW 13
ROW 1
FRONT VIEW
(SCALE: 1/4)
59.85
59.80
59.80 (9)
43.85
28.90
14.45
10.07
-6 (22 PLACES) NOTE POSITIONING
-10 (11 PLACES)
-12 (2 PLACES)
-B ASSY
DETAIL I
(SCALE: 1/1)
(TYPICAL 22 PLACES)
.10 REF
.261 .250 DIA HOLE LOCATE TO MATCH -6
NAS1104-5
NAS679A4W
AN960416L
(4 PLACES)
BACB30LU3-6-3
NAS679A3W
AN960-10L
.195 .190 DIA HOLE
CSK 100° x .400 .390 D A
(2 PLACES)
SECTION E-E (TYPICAL)
(SCALE: 1/1)
SUPPORT STRUCTURE ASSEMBLY - THERMAL PROTECTION SYSTEM
SK11-5085-105
116

Figure 7-5:


D180-15093-1
BOTTOM VIEW
(SCALE: 1/4)
(-5 OMITTED FOR CLARITY)
SIDE VIEW
(SCALE: 1/4)
PLAN VIEW
(SCALE: 1/4)
-1 ASSEMBLY
VIEW A-A
(SCALE: 1/4)
SECTION B-B
(SCALE: 1/1)
(TYPICAL)
SECTION C-C
(SCALE: 1/1)
(TYPICAL)
FASTENER LOCATIONS
.254 .250 DIA HOLE
NAS1104-6
NAS679A4W
AN960C416L
.261 .250 DIA HOLE THRU 3 TO MATCH 5
NAS5174-6
NAS679C4W
41.20
40.00
52.89
43.55
28.90
14.45
10.76 (TYP)
6.55
2.50
.55 (TYP)
.10 (TYP)
.60
SUPPORT STRUCTURE ASSEMBLY - THERMAL PROTECTION SYSTEM
BOEING
SK11-5085-105
Figure 7-4:

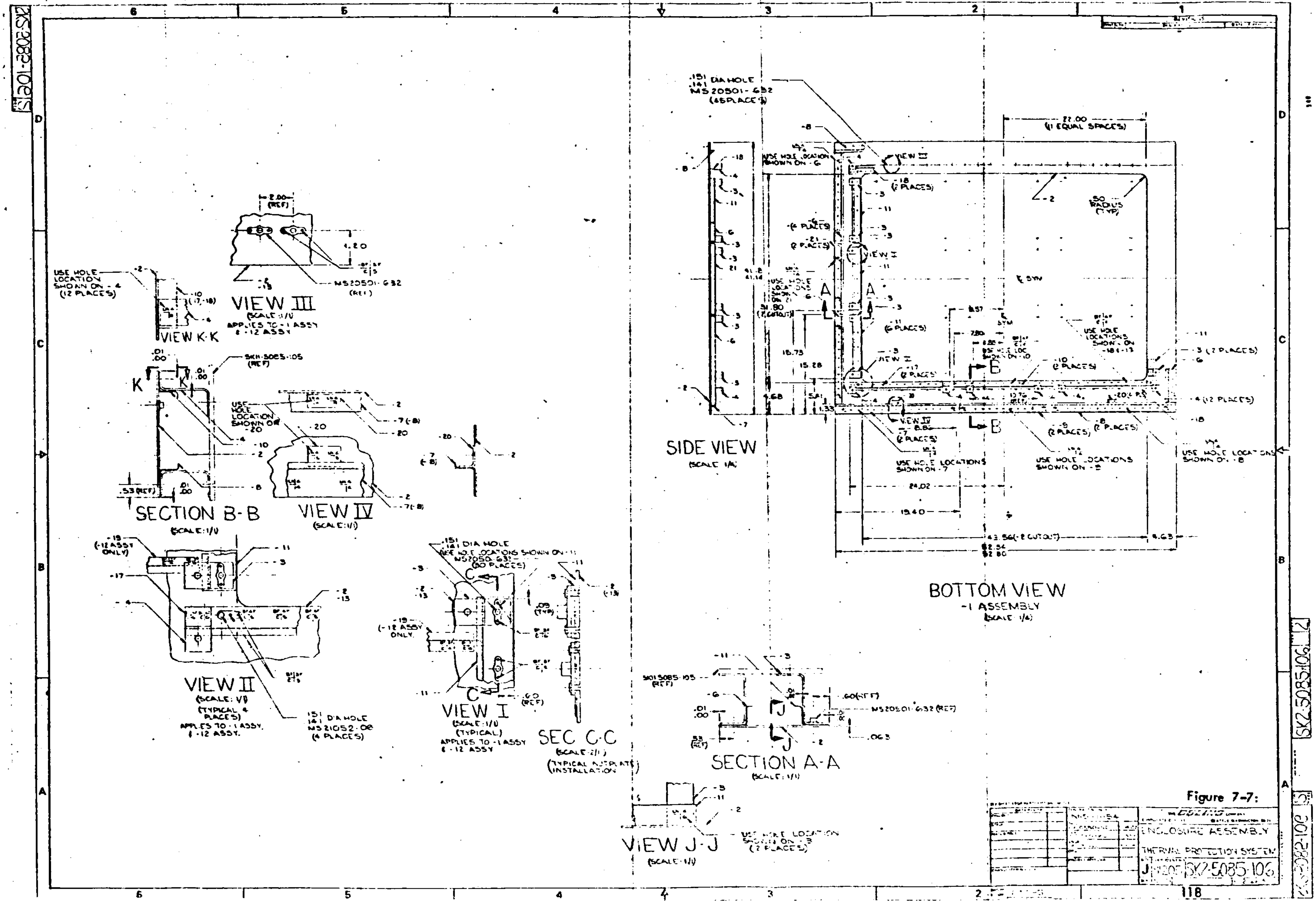

SK2-5085-106
VIEW III
VIEW K-K
SECTION B-B
VIEW IV
VIEW II
VIEW I
SEC C-C
SIDE VIEW
BOTTOM VIEW
-1 ASSEMBLY
SECTION A-A
VIEW J-J
ENCLOSURE ASSEMBLY
THERMAL PROTECTION SYSTEM
SK2-5085-106

Figure 7-7:

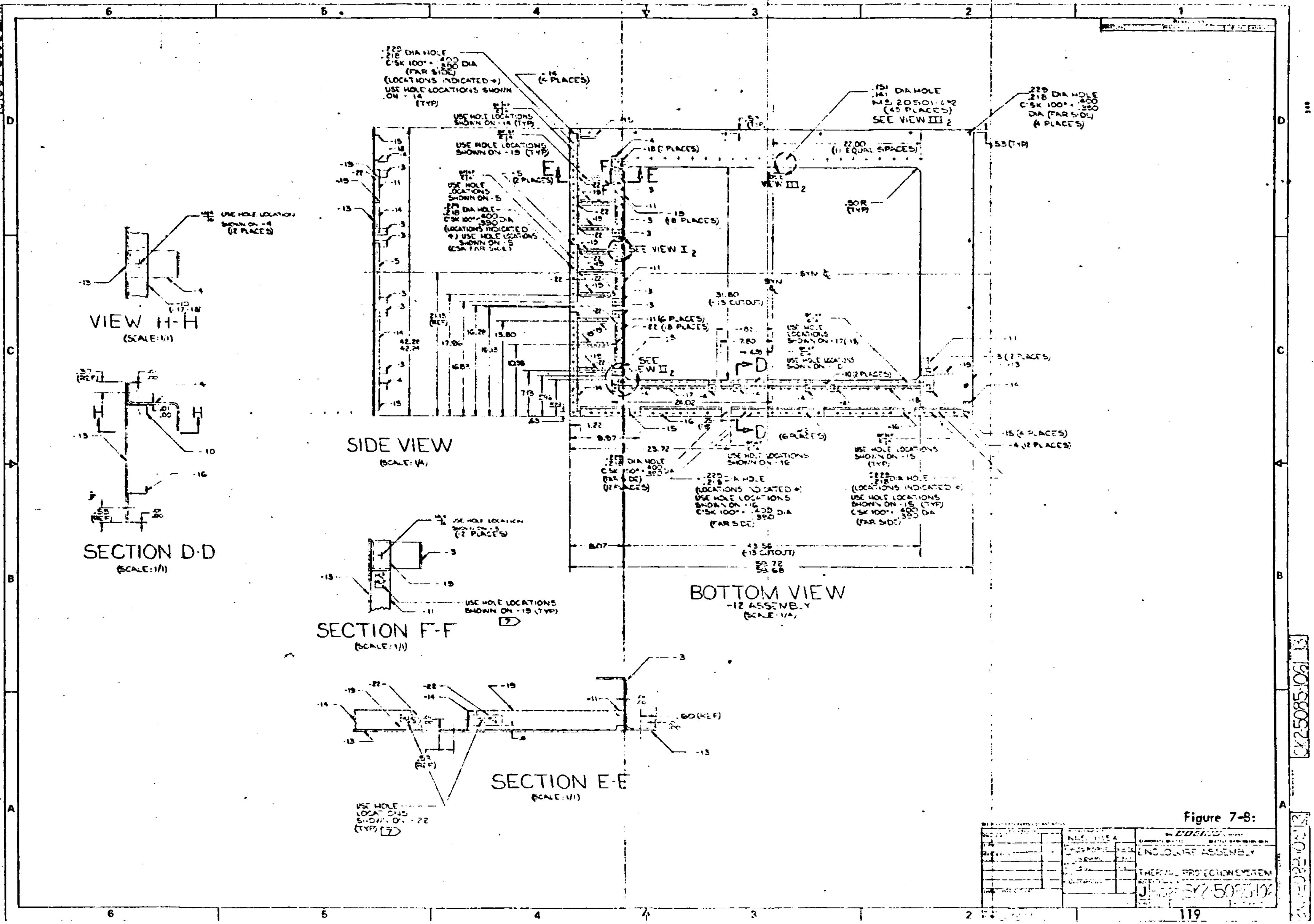
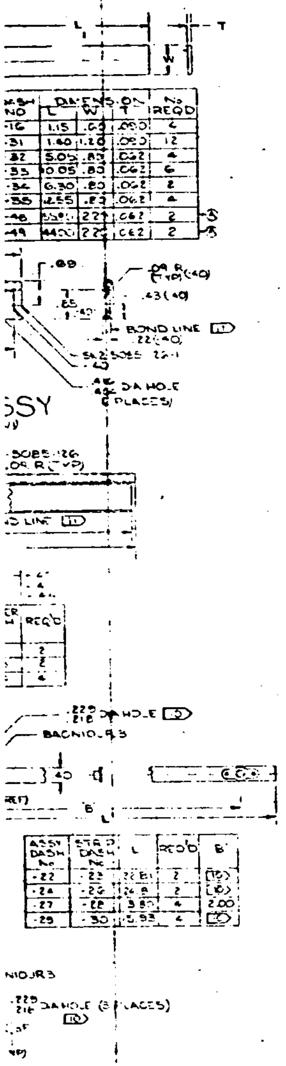

VIEW H-H
(SCALE: 1/1)
SECTION D-D
(SCALE: 1/1)
SIDE VIEW
(SCALE: 1/4)
BOTTOM VIEW
-12 ASSEMBLY
(SCALE: 1/4)
SECTION F-F
(SCALE: 1/1)
SECTION E-E
(SCALE: 1/1)
SEE VIEW III 2
SEE VIEW I 2
SEE VIEW II 2
USE HOLE LOCATIONS SHOWN ON -15 (TYP)
USE HOLE LOCATIONS SHOWN ON -16
ENCLOSURE ASSEMBLY
THERMAL PROTECTION SYSTEM

Figure 7-8:



DASH NO	L	W	T	NO REQD
-16	1.15	.63	.090	4
-31	1.40	1.20	.090	12
-32	5.05	.80	.062	4
-33	10.05	.80	.062	6
-34	6.30	.80	.062	2
-35	2.55	.80	.062	4
-46	5.50	2.27	.062	2
-49	4.40	2.27	.062	2

ASSY DASH NO	STRIP DASH NO	L	REQ'D	B
-22	-23	22.8	2	15
-24	-26	24.8	2	16
-27	-28	3.80	4	2.00
-29	-30	5.93	4	15

1. AT LOCATIONS INDICATED BY 'X' IN PLAN VIEW -1 & -2 ASSYS, EXTEND RADIAL LINES THRU SK11-5085-105-1 & -8 ASSYS CENTER AND EXISTING HOLE LOCATIONS. REMOVE NAS1104 BOLT & SK11-5085-105-7, LOCATE & DRILL HOLE ALONG RADIAL LINES AS SHOWN IN DETAIL I. IT WILL BE REQUIRED TO SCRIBE CENTER LINES ON SK11-5085-105-1 & 8 ASSYS & RADIAL LINE AT HOLE LOCATIONS.
2. AT LOCATIONS INDICATED BY 'Y' IN PLAN VIEW -1 & -2 ASSYS MARK HOLE LOCATIONS FROM SK2-5085-106-1 OR -12 (ENCLOSURE ASSYS) AFTER POSITIONING ASSYS PER 14. EXTEND RADIAL LINES THRU MARKED LOCATIONS. LOCATE & DRILL HOLE AS SHOWN IN DETAIL I. NO EXISTING HOLE AT THESE LOCATIONS.
3. CHEM MILL (INCONEL) PER BAC 5792.
4. CHEM MILL (TITANIUM) PER BAC 5842.
5. AT LOCATIONS WHERE -14 (RADIUS FILLER) IS USED, SUBSTITUTE AN NAS 601-12 FOR THE NAS 601-8 BOLT. DRILL 3/32 DIA HOLE THRU -14 WHERE NEEDED. SEE DETAIL III FOR TYPICAL -14 USAGE.
6. INCONEL 718 SHEET PER AMS 5596
7. INCONEL 600 SHEET PER MIL-N-6840
8. INCONEL SHEET 750-A PER MIL-N-7786 ANNEALED
9. APPLY TEFLON TAPE, HIGH TEMP SILICONE ADHESIVE SUPPLIED BY ENGR. ADD ADDITIONAL LAYERS AS REQD TO MEET SPECIFIED THICKNESS.
10. USE EXISTING HOLE LOCATIONS ON SK2-5085-106-1 TO LOCATE NUTPLATES, AND HOLES ON ALL SEAL & NUTPLATE ASSY NOT INDICATED.
11. BOND PER BAC 5010, TYPE 60. PRIME METAL WITH RTV 1200 PRIMER OR EQUIV.
12. .375 DIA × .035 WALL, 304 CRES TUBE PER MIL-T-8504
13. 2024-T3 ALUM STRIP OR SHEET. ANY ALUM SUBSTITUTION APPROVED BY ENGR.
14. ENCLOSURE ℄ SHALL COINCIDE WITH SUPPORT ASSY ℄ WITHIN ±.020
15. PANEL ASSY (80-0193) ℄ BETWEEN INNER OMEGA JOINTS SHALL COINCIDE WITH ENCLOSURE ℄ WITHIN ±.020
16. INSTALLATION TORQUE 9-12 IN-LBS.
17. INSTALLATION TORQUE 12-15 IN-LBS.
18. INSTALLATION TORQUE 45-55 IN-LBS.
19. TRIM -38 ASSY AS REQUIRED AFTER INSTALLING ALL OTHER SEAL ASSYS.

NOTES

Ref	Qty	Part or Identifying No.	Nomenclature or Description	Zone	Material and Specification
-27	2	BACN10JR3	NUTPLATE		
✓	1	-47	FILLER		.025 × 1.20 × 31.86 (8)
✓	84	NAS 221 30-3	BOLT		
✓ ✓	AR	NAS 601-12	BOLT		
✓ ✓	36	NAS679A06	NUT		
✓ ✓	36	NAS601-6	BOLT		
	6	BACN10JR3	NUTPLATE		
	1	BACN10JR3	NUTPLATE		
	2	BACN10YB3F	NUTPLATE		
	AR	SK2-5085-26-1	EXTRUDED SEAL		FURNISHED BY ENGR
-18	2	-46	OPP -45	B7-1	
-17	2	-45	CARRIER	B7-1	.025 × 3.70 × 4.55 (12)
-39	4	-44		C5-1	.025 × 1.30 × 15.86
-37	2	-43			.025 × 1.30 × 24.74
-36	2	-42			.025 × 1.30 × 22.74
-38	4	-40	CARRIER		.025 × 1.30 × 3.20 (12)
✓	4	-39	SEAL ASSY		
✓	4	-38			
✓	2	-37			
✓	2	-36	SEAL ASSY	C5-1	
✓	4	-35	FILLER	D4-1	.062 × .80 × 2.55 (13)
✓	2	-34			.062 × .80 × 6.40
✓	6	-33			.062 × .80 × 10.00
✓	4	-32			.062 × .80 × 5.00
✓	12	-31	FILLER	D4-1	.090 × .80 × 1.40 (13)
-29	4	-30	NUTPLATE STRIP	B5-1	.040 × .40 × 5.93 (13)
✓	4	-29	NUTPLATE ASSY	B5-1	
-27	4	-28	NUTPLATE STRIP	B5-1	.040 × .40 × 3.80 (13)
✓	4	-27	NUTPLATE ASSY	B5-1	
-24	2	-26	NUTPLATE STRIP	B5-1	.040 × .40 × 24.8 (13)
✓	2	-24	NUTPLATE ASSY	B5-1	
-22	2	-23	NUTPLATE STRIP	B5-1	.040 × .40 × 22.8 (13)
✓	2	-22	NUTPLATE ASSY	B5-1	
✓	1	SK2-5085-106-12	ENCLOSURE ASSY		
✓	1	SK2-5085-106-1	ENCLOSURE ASSY		
✓	1	SK11-5085-105-8	SUPPORT ASSY		
✓	1	SK11-5085-105-1	SUPPORT ASSY		
✓	2	80-0193-2	PANEL ASSY		SERIAL NUMBERS 4 & 5
✓	1	80-0193-5	PANEL ASSY		SERIAL NUMBER 5
✓	28	NAS1304-7	BOLT		
✓ ✓	80	NAS1003-10	BOLT		
✓	46	NAS679A4	NUT		
-19 -20	2	-21	NUTPLATE STRIP	B5-1	.040 × 2.60 × 5.40 (13)
✓	2	-20	OPP -19	B5-1	
✓	2	-19	NUTPLATE ASSY	B5-1	
✓	2	-18	OPP -17	B6-1	
✓	2	-17	SEAL ASSY CORNER	B6-1	
✓	4	-16	FILLER	D5	.090 × .60 × 1.15 (13)
✓		-15	SPACER	B6	(12)
✓ ✓	AR	-14	FILLER RADIUS	B6-1	(3) .20 × 1.00 × 1.00
✓ ✓	2	-13	SEAL STRIP	C6-1	(8) .010 × .50 × .25
✓ ✓	4	-12	SEAL STRIP	C6-1	(8) .010 × .50 × 2.85
✓ ✓	1	-11	COVER, TE	C6	.010 × .25 × 32.68 (8)
✓ ✓	1	-10	FILLER	B5	(6) .025 × 1.60 × 32.68
✓ ✓	1	-9	COVER, LE	A5-1	(6) .025 × 2.20 × 30.96
✓ ✓	1	-8	OPP -7	C6-1	(7)
✓	1	-7	COVER, SIDE	C6	(7) .062 × 2.10 × 13.83
✓ ✓	2	-6	COVER, SIDE	C6	(7) .062 × 2.10 × 13.83
✓ ✓	2	-5	COVER, SIDE	C6-1	(7) .062 × 2.10 × 17.90
		-4	SPACER		(7)
✓		-3	WASHER	B6	(7) .062 × .75 × .75
		-2	[illegible] ASSEMBLY	B6-1	
	5	-1	[illegible] TEST ASSEMBLY	B6-2	
		PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION

PARTS LIST

✓	2	-49	EDGE SEAL		(7)	A
✓	2	-48	EDGE SEAL		(7)	A

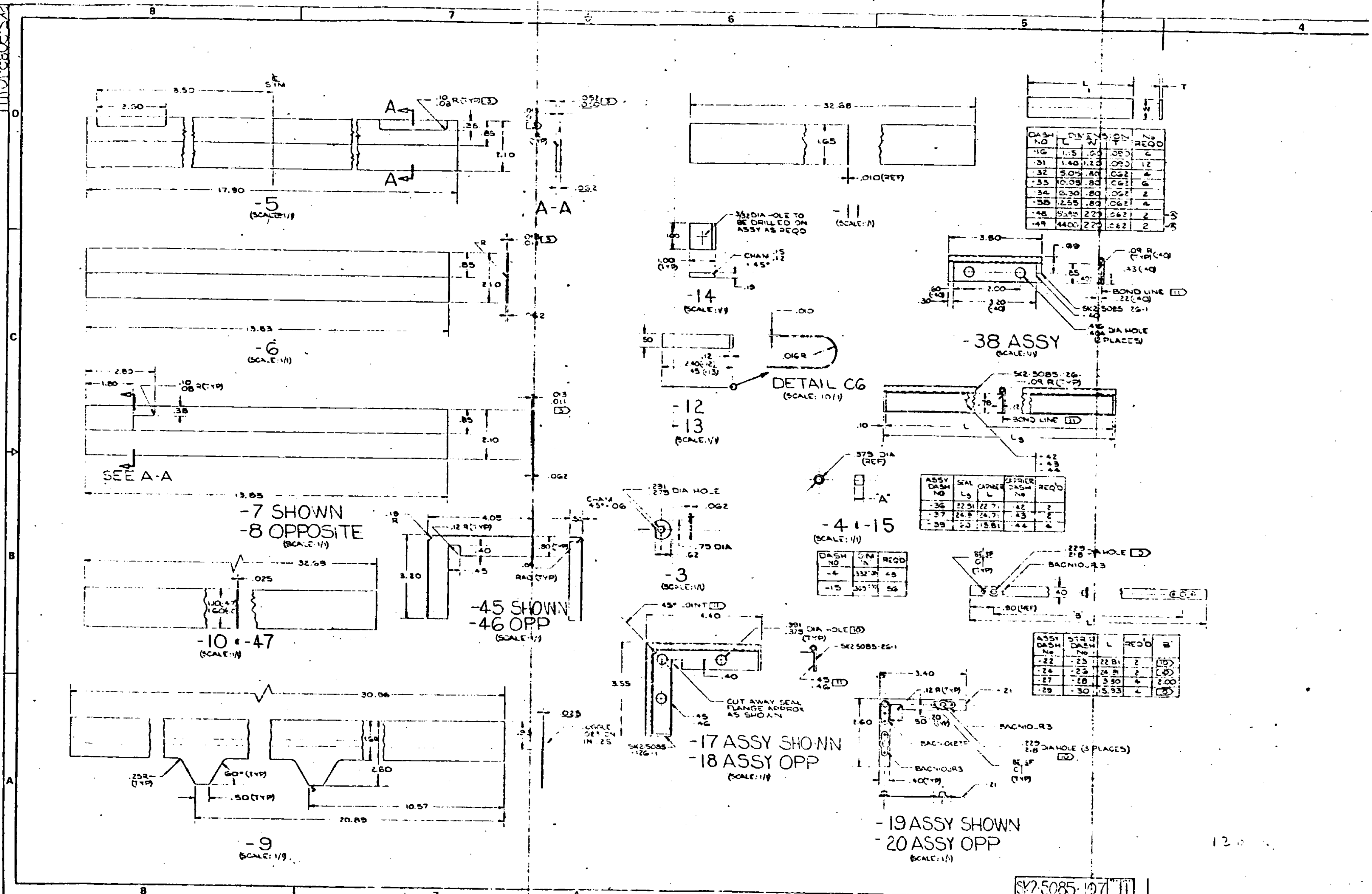
BOEING

TPS ... PROTECTION SYSTEM

J SK2-5085-107

120

SK2-5085-107 A 1



DASH NO	DIMENSION L	DIMENSION W	DIMENSION T	No REQD
-16	1.15	.60	.080	4
-31	1.40	1.20	.080	12
-32	5.05	.80	.062	4
-33	10.09	.80	.062	6
-34	6.30	.80	.062	2
-35	2.55	.80	.062	4
-48	52.95	2.29	.062	2
-49	44.00	2.29	.062	2

ASSY DASH NO	SEAL L_S	CARRIER L	CARRIER DASH NO	REQ'D
-36	22.91	22.71	-42	2
-37	24.9	24.71	-43	2
-39	20	19.81	-44	4

DASH NO	DIM "A"	REQD
-4	.332	48
-15	.365	56

ASSY DASH No	STR'G DASH No	L	REQ'D	"B"
-22	-23	22.81	2	15
-24	-26	24.81	2	9
-27	-28	3.90	4	2.00
-29	-30	15.93	4	5

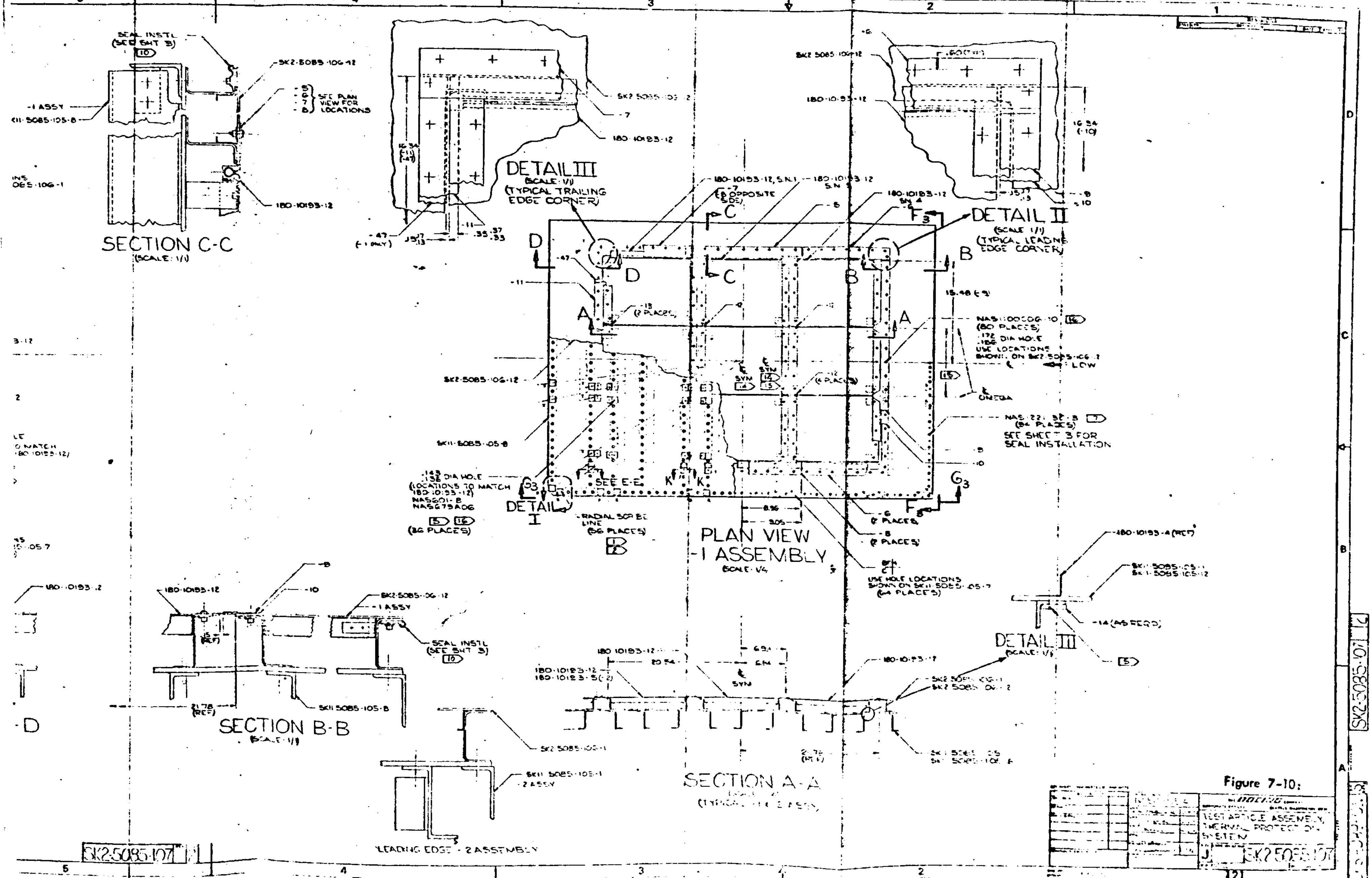
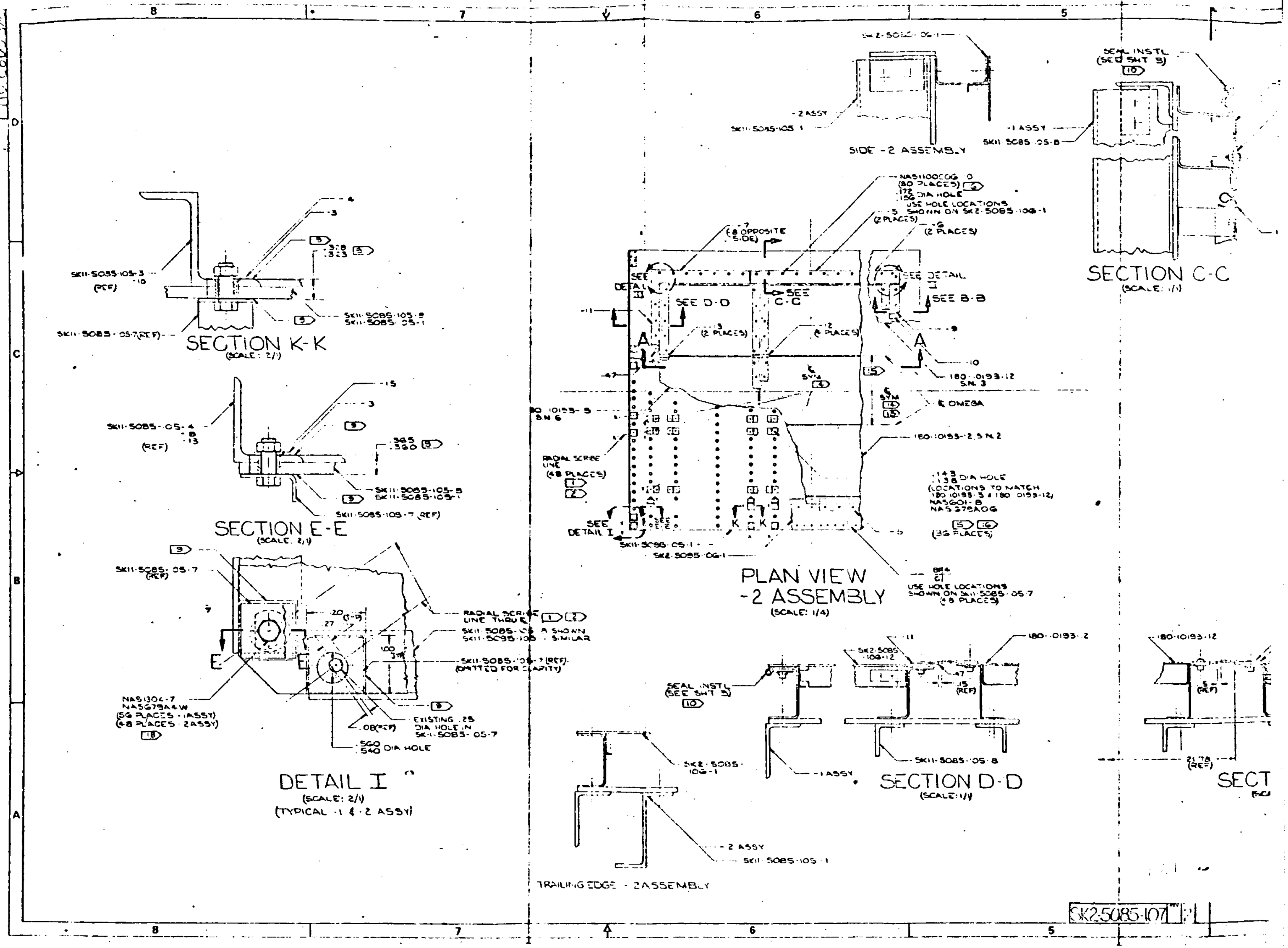

SECTION C-C
(SCALE: 1/1)
DETAIL III
(SCALE: 1/1)
(TYPICAL TRAILING EDGE CORNER)
DETAIL II
(SCALE 1/1)
(TYPICAL LEADING EDGE CORNER)
PLAN VIEW
-1 ASSEMBLY
SCALE: 1/4
DETAIL I
SECTION B-B
SECTION A-A
LEADING EDGE - 2 ASSEMBLY
SEE SHEET 3 FOR SEAL INSTALLATION
TEST ARTICLE ASSEMBLY, THERMAL PROTECTION SYSTEM
SK2-5085-107

Figure 7-10:


SECTION K-K
(SCALE: 2/1)
SECTION E-E
(SCALE: 2/1)
DETAIL I
(SCALE: 2/1)
(TYPICAL -1 & -2 ASSY)
SIDE -2 ASSEMBLY
SECTION C-C
(SCALE: 1/1)
PLAN VIEW
-2 ASSEMBLY
(SCALE: 1/4)
SECTION D-D
(SCALE: 1/1)
TRAILING EDGE - 2 ASSEMBLY
SK11-5085-105-3
SK11-5085-05-7 (REF)
SK11-5085-105-8
SK11-5085-05-1
SK11-5085-05-4
SK11-5085-105-7 (REF)
NAS1304-7
NAS679A4W
(56 PLACES -1 ASSY)
(48 PLACES -2 ASSY)
.560
.540 DIA HOLE
EXISTING .25 DIA HOLE IN SK11-5085-05-7
RADIAL SCRIBE LINE THRU ℄
SK11-5085-105-1
SK11-5085-05-8
SEAL INSTL (SEE SHT 3)
USE HOLE LOCATIONS SHOWN ON SK2-5085-106-1
USE HOLE LOCATIONS SHOWN ON SK11-5085-05-7
180-10193-12
180-10193-2
℄ OMEGA
SK2-5085-106-1
SK2-5085-106-12
SK2-5085-107

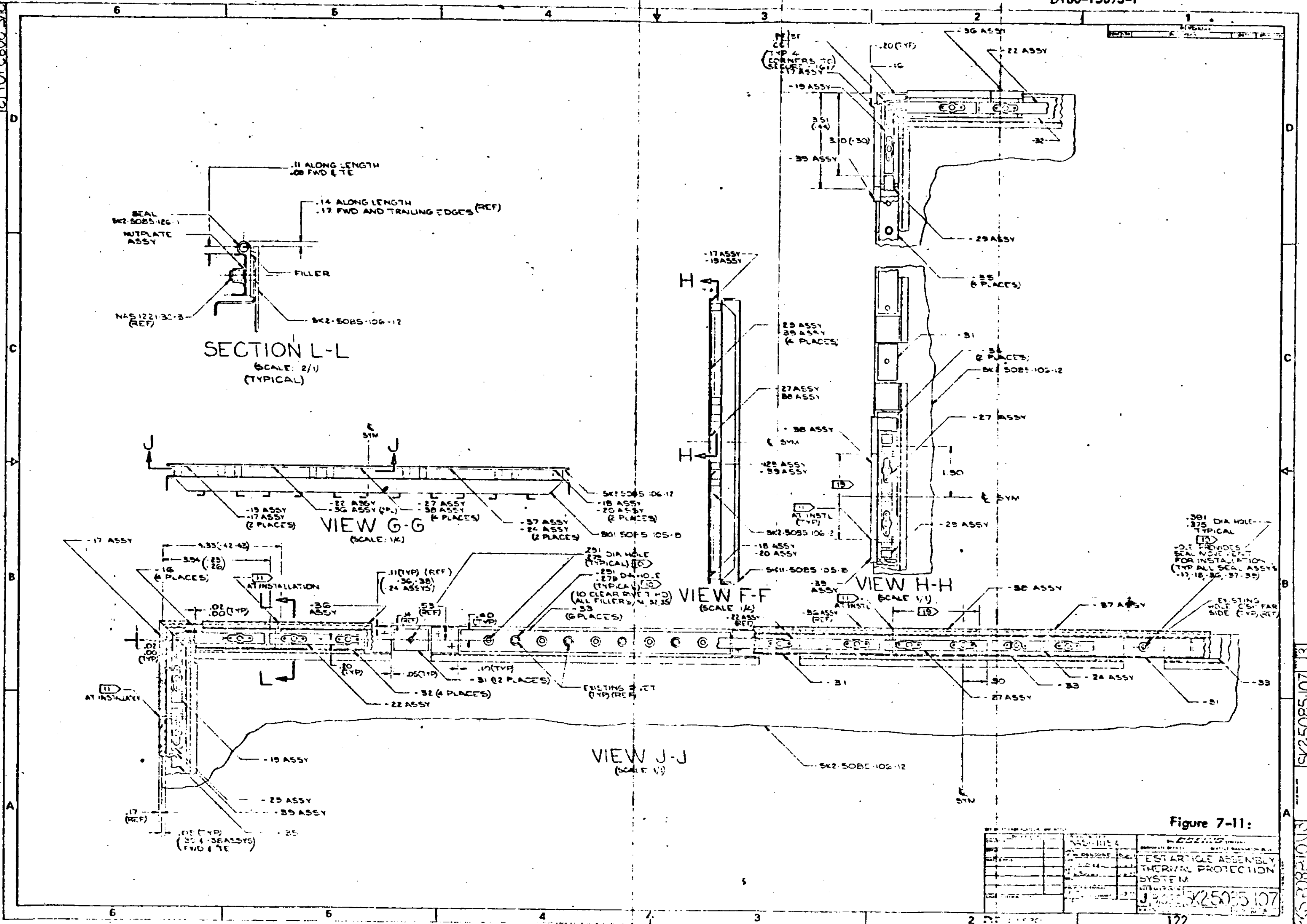


Figure 7-11:

TEST ARTICLE ASSEMBLY
THERMAL PROTECTION
SYSTEM

SK2-5085-107

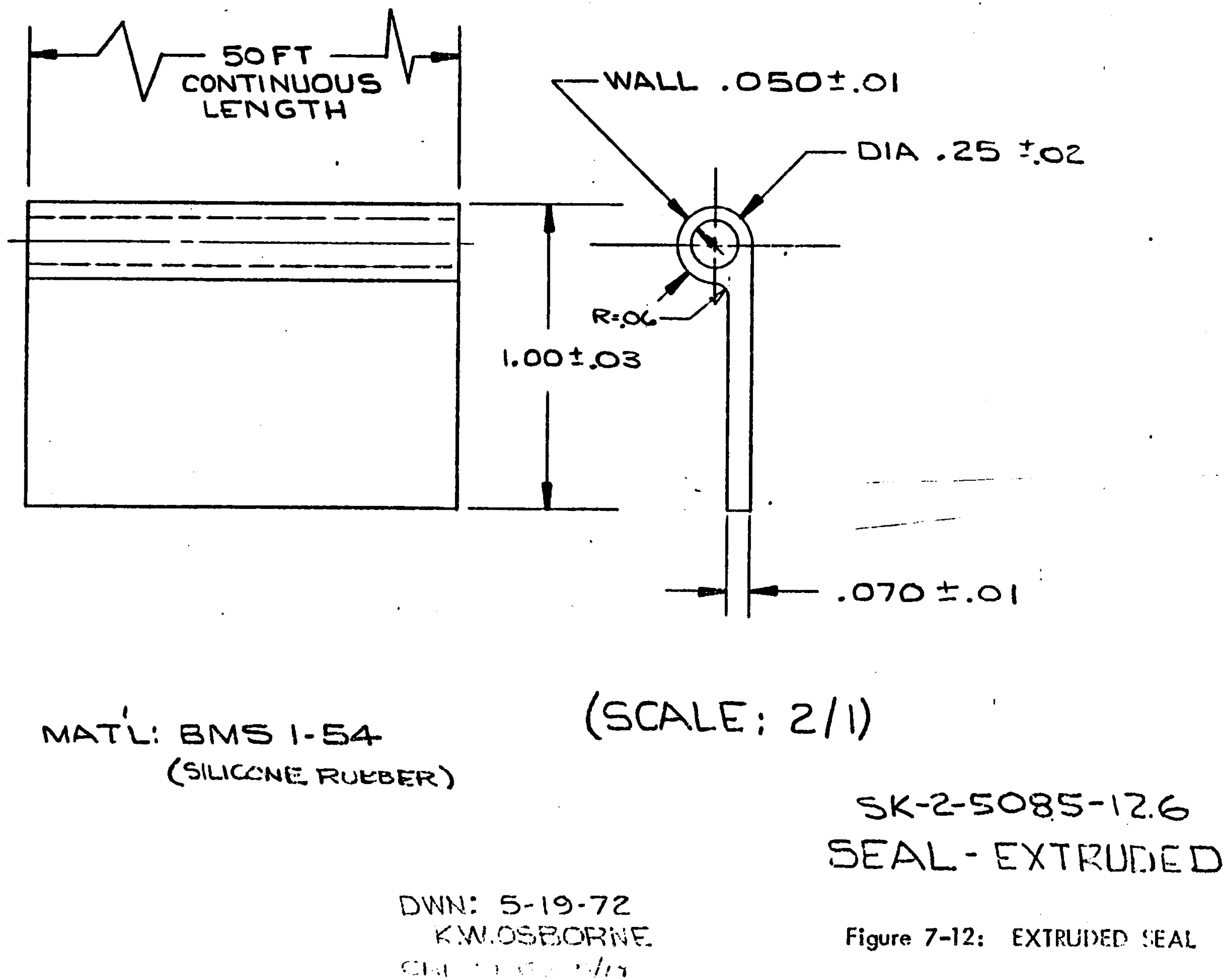


Figure 7-12: EXTRUDED SEAL

8.0 REFERENCES

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THE BOEING COMPANY

NUMBER
REV LTR

ACTIVE SHEET RECORD

SHEET NUMBER	REV LTR	ADDED SHEETS SHEET NUMBER	REV LTR	ADDED SHEETS SHEET NUMBER	REV LTR	SHEET NUMBER	REV LTR	ADDED SHEETS SHEET NUMBER	REV LTR	ADDED SHEETS SHEET NUMBER	REV LTR
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12						52					
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ACTIVE SHEET RECORD

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